Understanding and Supporting Anticipatory Driving in Automated Vehicles

by

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Abstract

With state-of-the-art driving automation technology available to the public (i.e., SAE Level 2 driving automation), drivers no longer need to control the vehicle continuously, but are still required to monitor the road and the automation, and take over control or adjust the automation's setting when necessary. Thus, many driving skills, such as anticipatory driving, which can allow drivers to predict potential traffic changes and respond to them in advance, can still enhance driving safety in automated vehicles. Anticipatory driving has already been found to be more prevalent among experienced drivers in non-automated vehicles. However, the factors influencing anticipatory driving in automated vehicles has not yet been investigated. Thus, this dissertation aims to understand anticipatory driving behaviors in automated vehicles and investigate displays that can support it.

Three driving simulator experiments were conducted. The first experiment investigated the relationships between anticipatory driving, distraction engagement, driving experience, and visual attention allocation in non-automated vehicles. The second experiment re-investigated the factors mentioned above in a simulated automated vehicle equipped with adaptive cruise control and lane keeping assistance. The third experiment investigated the effectiveness of two displays in supporting anticipatory driving among experienced and novice drivers in automated vehicles,

i.e., a TORAC display with takeover request (TOR) and automation capability (AC) information, and a STTORAC display with surrounding traffic (ST) information in addition to the TORAC display.

Results show that in both automated and non-automated vehicles, experienced drivers exhibited more anticipatory driving behaviors, and distraction engagement impeded anticipatory driving for both novice and experienced drivers. Further, allocating more visual attention toward cues indicating upcoming events increased the odds of exhibiting anticipatory driving behaviors in non-automated vehicles. For automated vehicles, it was found that drivers' reliance on automation might have a larger impact on the performance of anticipatory driving compared with visual attention to cues. The TORAC display led to less anticipatory driving in automated vehicles, possibly because it led to over-reliance on automation. Providing additional context information in the STTORAC display presumably supported drivers' anticipation of potential traffic conflicts.

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Chapter 1

1 Introduction

1.1 Anticipatory driving: A competence that matters in automated vehicles

According to the National Motor Vehicle Crash Survey conducted from 2005 to 2007, human error accounts for around 94% of crashes (Singh, 2018). Therefore, automating elements of the driving task was proposed as a solution to reduce the number of crashes attributed to human error. In recent years, advancements in sensor, computation, and control technologies have made automated vehicles a reality. For example, Tesla, Google, Nissan, Ford, and Audi have all released vehicles with semi-automated driving capabilities, and launched plans for manufacturing autonomous vehicles in the coming few years. Moreover, Uber is now aiming for a global rollout of autonomous taxis in the near future (Uber Technologies Inc., 2020). However, driving automation is not a panacea, at least with the currently limited capabilities it provides. Although automation can reduce the workload of operators, increase productivity, and generate safety and mobility benefits, it may cause problems and lead to unsafe situations if not designed appropriately (Litman, 2018; Wickens et al., 2015). Incidentally, over the past few years, we have witnessed many automation-related crashes (e.g., Boudette, 2016; National Transportation Safety Board, 2018a, 2018b), which remind us that the automated driving systems are still less than ideal.

Driving safety in automated vehicles relies on more than technical developments. Until fully automated vehicles become a reality, drivers are still responsible for driving safety in some capacity. Despite the ambitious plans of vehicle manufacturers, vehicle technologies usually take two to five decades to saturate their potential market. Currently, SAE level-2 (SAE On-Road Automated Vehicle Standards Committee, 2018) is still the state-of-the-art vehicle-automation technology available in the market (see Table 1 for more details about SAE automation levels). At this level of automation, the automated driving systems can free up drivers from physically controlling the vehicle but still require drivers to actively monitor the systems and take action promptly in case of safety-critical events that are beyond the automation's capability. Thus, driving safety in automated vehicles arguably relies more on drivers' capability to allocate their attention appropriately and perceive hazards than their skills in vehicle handling.

Table 1. SAE Levels of automation levels

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

Human-automation interaction research has demonstrated that human operators are not good at performing supervisory tasks (Bainbridge, 1983; Litman, 2018). For example, it was found in a driving simulator that with increasing automation (from manual driving to either longitudinal or lateral control being automated, to both longitudinal and lateral control being automated), drivers shift increasingly more of their attention away from the driving task and focus more on secondary tasks that are non-driving-related (Carsten et al., 2012). A recent naturalistic study with Tesla Model S by Gaspar and Carney (2019) also found that drivers had longer mean and maximum off-road glance durations when the "Autopilot" function (which automated lateral and longitudinal control of the vehicle) was engaged compared to when the function was not engaged.

Although the research cited above has shown differences in off-road glances and visual attention to non-driving tasks between automated and non-automated vehicles (e.g., Carsten et al., 2012; Gaspar & Carney, 2019), there are very few studies that have investigated how drivers allocate their attention in automated vehicles in order to perceive and assess the traffic situation or automation states. A few driving simulator studies have shown that when approaching a predictable automation failure, participants allocated more attention to cues that may indicate the state of the automation or future traffic situations. For example, in a driving simulator study, DeGuzman, Hopkins and Donmez (2020) found that while driving with ACC (Adaptive Cruise Control) and LKA (Lane Keeping Assistant) engaged, drivers looked more at the roadway and less at a non-driving task when there were cues in the environment (breaks in the lane markings) indicating that the automation may fail. In another driving simulator study, Dogan et al. (2017) found that drivers looked more at the speedometer when they approached a speed limit at which they were told the automation would fail. These results suggest that drivers were able to anticipate the potential for a failure and re-allocate their attention accordingly. However, the areas that indicated the upcoming automation failures are relatively easy to identify (e.g., the upper speed limit of ACC or breaks in the lane markings) in these studies. These studies did not consider automation failures that may be triggered by traffic situations that dynamically evolve on the road. Drivers who can anticipate how the traffic may evolve based on anticipatory cues that facilitate the anticipation of upcoming events might be at an advantage to intervene when automation fails. The ability to anticipate future traffic events is considered to be a significant element of driver competence that can improve with driving experience in non-automated vehicles (Jackson, Chapman, & Crundall, 2009; Sagberg & Bjørnskau, 2006; Stahl, Donmez, & Jamieson, 2014, 2016), but has yet to be investigated in automated vehicles.

The majority of previous studies used the lens of hazard perception (see details of related studies in Appendix A) to study anticipatory driving, e.g., Sagberg and Bjørnskau (2006) and Jackson et al. (2009). Hazard perception has been defined from different perspectives, for example, "*situation awareness for dangerous situations in the traffic environment* " (Horswill & McKenna, 2004, p. 155) and "*the process of detecting, evaluating and responding to dangerous events on the road that have a high likelihood of leading to a collision.*" (Crundall et al., 2012, p. 600). However, anticipatory driving is not identical to hazard perception. Stahl et al. (2014) provided a working definition for anticipatory driving in non-automated vehicles as "*a manifestation of a high-level cognitive competence that describes the identification of stereotypical traffic situations on a tactical level through the perception of characteristic cues, and thereby allows for the efficient positioning of a vehicle for probable, upcoming changes in* *traffic*." (Stahl et al., 2014, p. 603). This definition scopes anticipation down to the tactical level (i.e., within seconds into the future) and suggests that anticipatory drivers can be cognitively prepared for future events but may or may not take action in response. The definition uses the word "efficient," which is context and driver dependent. That is, the action can be both aggressive or defensive for "efficient" vehicle positioning, depending on the driver's goals (e.g., maximizing eco-driving, increasing safety margins, minimizing effort, or reducing travel times). Therefore, anticipatory driving is not just limited to enhancing driving safety and should not be studied solely from the safety perspective (e.g., hazard perception) as is the case for most literature on hazard perception (e.g., Burge & Chaparro, 2012; Underwood, Ngai, & Underwood, 2013).

Further, hazard perception studies traditionally utilized abrupt hazards (e.g., Chapman & Underwood, 1998), where standard hazard perception tests were used to record reaction times to a sudden onset hazard, a situation that does not allow for anticipation. Other studies on gradual-onset hazards (e.g., Crundall et al., 2012; Lee et al., 2008; Muttart, Fisher, & Pollatsek, 2014) provided an advancement over earlier hazard perception studies by utilizing scenarios that involved what Crundall et al. (2012) named environmental prediction hazards, e.g., child steps into the road behind a parked van, which could be used by drivers to anticipate a hidden hazard. For the environmental prediction hazard, the two stimuli, precursor (i.e., van) and hazard (i.e., child) are indirectly related, but there is a possibility that they occur together. Thus, the perception of the hazard requires experience or knowledge of the statistical probabilities of certain stimuli occurring together in the driving scene. In a driving simulator study, Crundall et al. (2012) also tested scenarios where the participants could anticipate the future behavior of a traffic agent (e.g., a car pulling in front of the participant vehicle) directly from the current behavior of that traffic agent (e.g., same car waiting on a side road). However, these hazard anticipation scenarios, which Crundall et al. (2012) named behavioral prediction hazards, still did not fully represent the complexities of traffic, where the action of a traffic agent is often dependent on the actions of other traffic agents. For example, another car approaching a stopped vehicle can provide a cue to the driver that the stopped vehicle may start moving due to perceived pressure from the vehicle behind. Arguably, more complex scenarios with causal links between the behaviors of different traffic agents such as the ones used by Pradhan et al. (2005) to study risk perception in a driving simulator, would better assess the high-level cognitive competence of anticipation in driving. To further explain the concept of anticipatory driving, a scenario that can enable anticipation of future traffic conflicts (i.e., an anticipatory scenario) is illustrated in Figure 1 with explanations provided below.

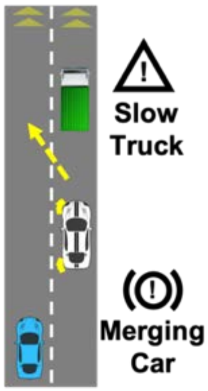


Figure 1. An example of scenarios that enable anticipatory driving

In the example scenario in Figure 1, a blue vehicle is traveling on the left lane of a highway and approaching a slow-moving truck (green) on the right lane. Another white vehicle following the truck on the right lane travels faster than the truck but slower than the blue vehicle. Because of the decreasing distance between the white vehicle and the truck, the white vehicle will have to slow down to avoid a collision with the truck or move to the left lane to pass the truck, the latter leading to a conflict with the blue vehicle. In this scenario, there is an “anticipatory cue” indicating a potential change in the traffic situation (i.e., the decreasing distance between the slow truck and the merging car), and an “event” that unambiguously indicates the change of the traffic situation, i.e., the merging of the white vehicle to the left, starting with its left signal onset.

In general, the onset of an event is marked by an action of any road agent that would unambiguously indicate its actions or driver’s intentions (e.g., the onset of the left directional signal of the white vehicle can express the driver’s intention to merge left). In contrast, anticipatory cues do not necessarily indicate a clear conflict. For example, the decreasing distance between the white vehicle and the truck may not necessarily lead to a left merging action of the white vehicle as the driver may also choose to slow down and wait for the blue vehicle to pass first, and then move to the left lane. If the driver of the blue vehicle takes an action before the event onset, then the action can be identified as a “pre-event action” and the driver can be regarded as exhibiting an anticipatory driving behavior (Stahl et al., 2014, 2016;

Stahl, Donmez, & Jamieson, 2019). In the above example, the pre-event actions include slowing down (e.g., by depressing the brake pedal) to allow more space for the white vehicle to merge left, or accelerating (e.g., by pressing the gas pedal) to pass the white vehicle before it signals left. Further, in automated vehicles, drivers' preparation to perform pre-event actions (i.e., pre-event preparation, for example, by moving hands or feet to prepare to takeover or change the settings of the automation) can also be considered as anticipatory driving behaviors. In non-automated vehicles, "preparations" are not considered, as drivers' hands are almost always on the steering wheel and foot is almost always on gas or brake pedal. However, it should be noted that anticipatory drivers who realize the potential traffic conflict may still choose not to act. In the example mentioned above, an anticipatory driver in the blue vehicle can decide to take no action before event onset, either because the driver believes that the blue vehicle could pass the white vehicle before it moves to the left lane, or the space is large enough for the white vehicle to merge in front. It is also possible that the driver simply decides to take no action until it becomes necessary to do so.

Using the framework of anticipatory driving described above, in two driving simulator studies, Stahl et al. (2014, 2016) found experienced drivers to exhibit more pre-event actions in non-automated vehicles when driving was the only task. Further, they showed that novice drivers could be supported to exhibit more pre-event actions through the use of in-vehicle information displays that highlighted upcoming potential traffic conflicts (Stahl et al., 2016). In these studies, drivers who acted before the event onset were identified to be exhibiting anticipatory driving behaviors. It is expected that being anticipatory would allow drivers more time to respond to potential traffic conflicts, compared to those who act reactively, as they can be able to "foresee" what might happen. The potential benefit in increased allowable response time before traffic conflict as a result of being anticipatory may especially improve driving safety in automated vehicles. This is because it usually takes several seconds for drivers to rebuild an awareness of upcoming hazards in automated vehicles, even with take-over requests (TORs) that alert the driver about the need to intervene (Gold, Damböck, Lorenz, et al., 2013; Mok et al., 2015), especially when drivers are distracted by non-driving tasks, as illustrated in both an instrumented vehicle (Naujoks et al., 2019) and in a driving simulator study (Shen & Neyens, 2017). If drivers in automated vehicles can be anticipatory, they would be able to prepare for or take actions earlier in response to the takeover events that require transfer of control from the automated driving system to the driver. However, to the best of our knowledge and as summarized in Appendix B, research is lacking for automated vehicles regarding factors that influence anticipatory driving and how to support this driving skill.

1.2 Driving experience, distraction and anticipatory driving in automated vehicles

Driving experience is one of the factors that was found to influence the performance of anticipatory driving in non-automated vehicles in driving simulator studies (Stahl et al., 2014, 2016, 2019), and may also affect anticipatory driving in automated vehicles with experienced drivers performing more anticipatory behaviors than novices. However, as drivers are freed up from continuously controlling the vehicle in automated vehicles, they are expected to have more spare attentional capacity compared to when operating non-automated vehicles, as suggested by several driving simulator studies summarized in Stanton and Young (1998). The spare capacity can especially benefit novice drivers in anticipation as limited cognitive and attentional capacity was suggested to be one of the reasons why novices were slower at perceiving hazards on the road, as captured in a video simulation study (Jackson et al., 2009). However, drivers were found to be more likely to shift their attention to non-driving tasks in automated vehicles (de Winter et al., 2014; Jamson et al., 2013; Rudin-Brown, Parker, & Malisia, 2003), thus, the spare attentional capacity afforded by automating vehicle control may not necessarily result in better anticipation. How experience affects anticipation in automated vehicles is an open research question that this dissertation aims to address.

Given that performance of anticipation depends on the perception of anticipatory cues, anticipation is expected to degrade with engagement in non-driving activities secondary to driving that compete for similar perceptual resources. However, even in non-automated vehicles no research has considered the effect of distraction engagement and its interaction with driving experience on anticipatory driving. In this regard, previous research in hazard perception can provide some guidance. Although limited, and mostly focused on auditory-vocal non-driving tasks, these studies indicated that cognitive distraction could potentially impair anticipation. For example, through video simulations, Mühl et al. (2019) found that additional cognitive load (imposed by two auditory-verbal tasks) can degrade experienced drivers' ability to anticipate the action of another vehicle. In a driving simulator, Biondi et al. (2015) found that with increased cognitive load (imposed by some common in-vehicle auditory-verbal tasks, e.g., talking on a hands-free cellphone), experienced drivers were more likely to fail to scan left and right directions visually in intersections. It should be noted that although the authors in Biondi et al. (2015) titled their paper as having captured "anticipatory glances", their glance analysis does not qualify as anticipation-related, according to the definition of anticipatory driving discussed previously. Instead of focusing on evolving traffic situations on the road, the authors only focused on two broad areas (i.e., left and right) that need to be scanned at an intersection. In another driving simulator study, Ebadi, Fisher and Roberts (2019) found that the engagement in an auditory-verbal hands-free cell phone task reduced the number of glances toward potential hazardous locations (e.g., crosswalk blocked by parked cars at intersections, and hidden driveways besides the road).

Driving, however, is a mainly visual-manual task, and distractions that require visual attention and manual action overlap the most with the driving task and hence are the most detrimental to safety (Dingus et al., 2016). A hazard anticipation study conducted in a simulator by Borowsky et al. (2015) found that participants who were momentarily visually obstructed often failed to continue scanning for a potential hazard after the obstruction was removed. However, although drivers were known to reduce their distraction engagement based on roadway demands (Schömig & Metz, 2013), the obstruction task in Borowsky et al. (2015) was not self-paced and thus removed the drivers' ability to moderate their distraction engagement based on their anticipation of a hazard. In instrumented vehicles, Lee et al. (2008) and Pradhan et al. (2011) investigated the impact of self-paced visual-manual tasks on drivers' performance when facing environmental prediction hazards. Their findings suggested that novice drivers were worse than their experienced parent drivers in hazard perception while distracted, but exhibited better hazard perception with accumulated driving experience. However, these studies did not have a comparable baseline condition with no distraction, and therefore did not report how the presence of visual-manual tasks could affect hazard anticipation for both novice and experienced drivers. Further, both Lee et al. (2008) and Pradhan et al. (2011) focused on scenarios with environmental prediction hazards (Crundall et al., 2012), which, as argued earlier, are limited in the study of anticipation in general. Given the limitations of these few existing studies, and the safety-relevance of visual-manual distractions, further research is needed to understand the effects of visual-manual distractions on anticipatory driving. This is another research question that this dissertation aims to address.

It is expected that experienced drivers' anticipatory behaviors would be affected less by distraction compared to novice drivers, at least in non-automated vehicles. This assumption is based on the findings of previous non-automated driving research, which found that experienced drivers exhibited potentially safer glance behaviors, both when distracted and not distracted, compared to novice drivers. For example, experienced drivers' fixations were found to cover a wider area on road in an instrumented vehicle (Mourant & Rockwell, 1972); they also were found in an instrumented vehicle to vary the width of their horizontal scanning to accommodate differing complexities in the roadway whereas novice drivers did not (Crundall & Underwood, 1998); and they were found in a simulator to fixate more on risky features of a scenario than novices (Pradhan et al., 2005). Even when engaged in a visual-manual non-driving task, experienced drivers had fewer risky off-road glances (i.e., longer than 3 seconds) than novices on road in an instrumented vehicle (Wikman, Nieminen, & Summala, 1998) and they committed fewer driving infractions when engaged in an auditory-verbal hands-free cell phone task in a driving simulator (Kass, Cole, & Stanny, 2007). The better visual scanning strategies among experienced drivers may facilitate their understanding of the emerging situations as they may notice the cues indicating future potential traffic conflicts earlier than novice drivers. Thus, it is expected that experienced drivers' anticipatory driving behavior may be affected less by distraction engagement compared to novice drivers, at least in non-automated vehicles.

Given the demonstrated and expected effects of experience and distraction engagement on anticipatory driving in non-automated vehicles, it is also important to consider their impact on anticipatory driving in automated vehicles. Thus, this dissertation investigates these two factors both for non-automated and automated vehicles. In addition, other automation-related factors may need to be considered and explored when studying anticipatory driving in automated vehicles. For example, it is expected that drivers need both an awareness of the surrounding traffic environment and an awareness of the automation's and vehicle's capabilities in order to predict the future traffic situation and decide on a course of action (i.e., whether to take over the control of the vehicle or to continue to delegate the vehicle control to the automation). Thus, drivers' understanding of the automation capability may affect their prediction of how automation will respond to the traffic conflicts and hence upcoming traffic development.

Moreover, drivers' trust in the automated driving systems was found in a simulator to affect their reliance and usage of the automated driving systems(Körber, Baseler, & Bengler, 2018), and thus can also influence anticipatory driving behaviors. Thus, this dissertation also considers these automation-related factors in the study of anticipation in automated vehicles.

1.3 Supporting anticipatory driving in automated vehicles

Automation has been suggested to be better at perceiving the kinematics information accurately (Stanton & Salmon, 2009; Young, Stanton, & Harris, 2007), and drivers to be better at understanding and predicting complex traffic situations, e.g., interpreting and anticipating the intent of other road agents (Walker, Stanton, & Salmon, 2015). Thus, anticipatory drivers can be a good supplement to automated driving systems, especially in situations that are beyond or may develop to be beyond the limits of automation. Conversely, if automation can provide accurate kinematic information about the surrounding traffic to drivers, drivers' capability to anticipate may be enhanced.

Although supporting anticipatory driving in automated vehicles has not yet been investigated, hazard perception research in non-automated vehicles can provide some guidance. For example, hazard perception training programs have been found to be effective in improving drivers' capability in noticing gradual-onset hazards in some studies (e.g., Pollatsek et al., 2006); while other studies argued that the effectiveness of such programs on actual anticipation performance is not obvious (Unverricht, Samuel, & Yamani, 2018). Further, most previous research has focused on the effectiveness of hazard perception training on novice drivers' performance. However, in automated vehicles, experienced drivers may also need to be supported, especially when drivers are distracted – a factor that was rarely considered in studies on hazard perception training. Although training has the potential to enhance anticipatory driving performance in automated vehicles, this dissertation investigates in-vehicle display design to enhance anticipatory driving in automated vehicles. In-vehicle displays have been widely investigated and have been found to improve drivers' capability in detecting hazards in both non-automated (e.g., Schall Jr et al., 2013) and automated vehicles (e.g., Langlois & Soualmi, 2016), and they have also been found to be effective in supporting anticipatory driving in non-automated vehicles (Stahl et al., 2016).

In automated vehicles, so far, most previous research has focused on the design of displays that can support drivers during takeover events that do not allow for the anticipation of traffic development. Takeover requests (TORs), which are alerts that warn drivers about the need for their intervention, have been among the most widely investigated displays (e.g., Louw et al., 2015; Melcher et al., 2015; Zeeb, Buchner, & Schrauf, 2015). TORs are intended to reduce the need for drivers to monitor the environment and have been found to be effective in facilitating transfers of control from the automation to the driver, for example, by decreasing driver's reaction time, as was suggested in a meta-analysis of 129 related studies (Zhang et al., 2019). However, TORs may not always be adequate in supporting drivers of automated vehicles: drivers may not always understand why a TOR has been issued (Naujoks et al., 2017), and may need some time even after responding to a TOR to regain awareness of the driving environment (Vlakveld et al., 2018; Vogelpohl et al., 2018). Further, the use of TORs may lead to an over-reliance on automation if the warnings are highly reliable (Lee & See, 2004) or to "cry-wolf" effects (Breznitz, 1984) if they have a high rate of false alarms. Therefore, when a TOR is issued, it may also be necessary to provide drivers with additional information to support them in identifying the need for their intervention and in performing the intervention. For example, in-vehicle displays can inform drivers about the limits (e.g., Seppelt & Lee, 2007) and the reliability (e.g., Helldin et al., 2013) of an automated driving system. In combination with TORs, such displays can help clarify to drivers why a TOR has been issued and increase their awareness of the situation (Naujoks & Neukum, 2014; Naujoks et al., 2015).

Although displays that combine TORs and information about the automation's status or capabilities have been demonstrated to support takeover responses (e.g., Zhang et al., 2019), they may not be adequate for supporting anticipatory driving, as anticipatory driving also requires an awareness of the surrounding traffic environment and an ability to project the development of the situation based on anticipatory cues. It has been shown that drivers of automated vehicles are less aware of the surrounding traffic situation compared to those in non-automated vehicles (Stanton & Young, 2005). Even in cases where automated vehicle drivers have glanced at relevant cues, drivers may still have problems in fully comprehending the situation in a timely manner (Lorenz, Kerschbaum, & Schumann, 2014). The consequential time loss increases the risk of wrong or delayed decisions by the driver. In fact, Merat and Jamson (2008) found that drivers in automated vehicles were slower to respond to anticipatory cues indicating a future traffic conflict (e.g., a vehicle merging into the driver's lane in front of the lead vehicle, indicating that the lead vehicle may brake) compared to drivers in non-automated vehicles in a driving simulator study. Thus, a display would also need to facilitate drivers' awareness of the traffic situation in order to support anticipation.

Surrounding traffic information can be incorporated into in-vehicle displays through intelligent connected vehicle (ICV) technologies. Previous research has shown safety benefits of ICV technologies for non-automated vehicles in facilitating anticipatory driving behaviors. For example, Stahl et al. (2016) showed that in-vehicle displays that highlight anticipatory cues from the environment, which can be gathered through vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication, are successful in facilitating anticipatory driving behaviors for novice drivers, who in general lack this skill (Stahl et al., 2014). Although such ICV-enabled displays may also help support automated vehicle drivers in anticipating events that may require their intervention, to the best of our knowledge, no research has focused on investigating such displays particularly for anticipatory driving in automated vehicles. This is also one of the research questions that this dissertation aims to address.

1.4 Research gaps and dissertation goals

In summary, three research gaps were identified in previous research that this dissertation aims to address:

1) Research Gap 1: Although the relationship between driving experience and anticipatory driving performance was studied in non-automated vehicles (e.g., Stahl et al., 2014, 2016, 2019), driving was the sole task in these studies. The influence of distraction, especially visual-manual distraction (imposed by a visual-manual secondary task that is non-driving-related) on anticipation, has yet to be investigated for non-automated vehicles. This thesis focused on visual-manual tasks, as they have been found to be the most detrimental to driving safety (Dingus et al., 2016).

2) Research Gap 2: Factors (e.g., driving experience and distractions) that may influence anticipatory driving in automated vehicles have not yet been investigated.

3) Research Gap 3: Providing drivers with takeover requests (TORs) along with information on driving automation capability has been associated with faster reactions to traffic events that

require driver intervention (e.g., Zhang et al., 2019). However, it is unclear what type of information should be used to support drivers in anticipating traffic events, so they can intervene or prepare to intervene proactively to avert conflicts in automated vehicles.

Thus, this dissertation focuses on understanding and supporting anticipatory driving in automated vehicles, and also extends the literature on anticipatory driving in non-automated vehicles regarding the effects of distractions on anticipation. The dissertation consists of three driving simulator experiments, focusing on the research gaps mentioned above, as illustrated in Figure 2. Experiment 1 and Experiment 2 focus on Research Gap 1 and Research Gap 2, and Experiment 3 focuses on Research Gap 3. In all three experiments, anticipatory driving behaviors (i.e., pre-event actions and pre-event preparations), visual behaviors preceding and during anticipatory scenarios, and drivers' subjective responses to questionnaires were collected and analyzed.

In the first experiment (Experiment 1), the relationships between visual-manual distraction, driving experience, visual attention allocation, and anticipatory driving in non-automated vehicles were investigated in a simulator experiment. The results from this experiment have been published as a journal article in *Human Factors: The Journal of the Human Factors and Ergonomics Society* (He & Donmez, 2020) and a conference proceeding article in the *Human Factors and Ergonomics Society 62nd Annual Meeting* (He & Donmez, 2018).

In the second experiment (Experiment 2), the relationships between visual-manual distraction, driving experience, visual attention allocation, and anticipatory driving were re-investigated in automated vehicles (i.e., equipped with ACC and LKA). Specifically, the experiment aimed to understand how the factors that influence anticipatory driving in non-automated vehicles affect anticipatory driving in automated vehicles. It also considered other potential factors that are automation-related (e.g., trust and reliance). At the time of this writing, this work will shortly be submitted to a journal.

The last experiment (Experiment 3) compared the effectiveness of two different display designs in supporting anticipatory driving in automated vehicles. One of the display designs (TORAC) combined TOR and automation capability (AC) information. This design idea had been widely adopted in previous automated driving research to facilitate transfers of control from the automation to the driver. Still, its influence on anticipatory driving has not been investigated.

The other display (STTORAC) was newly designed, and it combined surrounding traffic (ST) information, TORs, and AC information. The additional ST information was expected to facilitate anticipatory driving in automated vehicles. At the time of this writing, this work is under consideration by *Accident Analysis and Prevention* requiring minor revision and modifications.

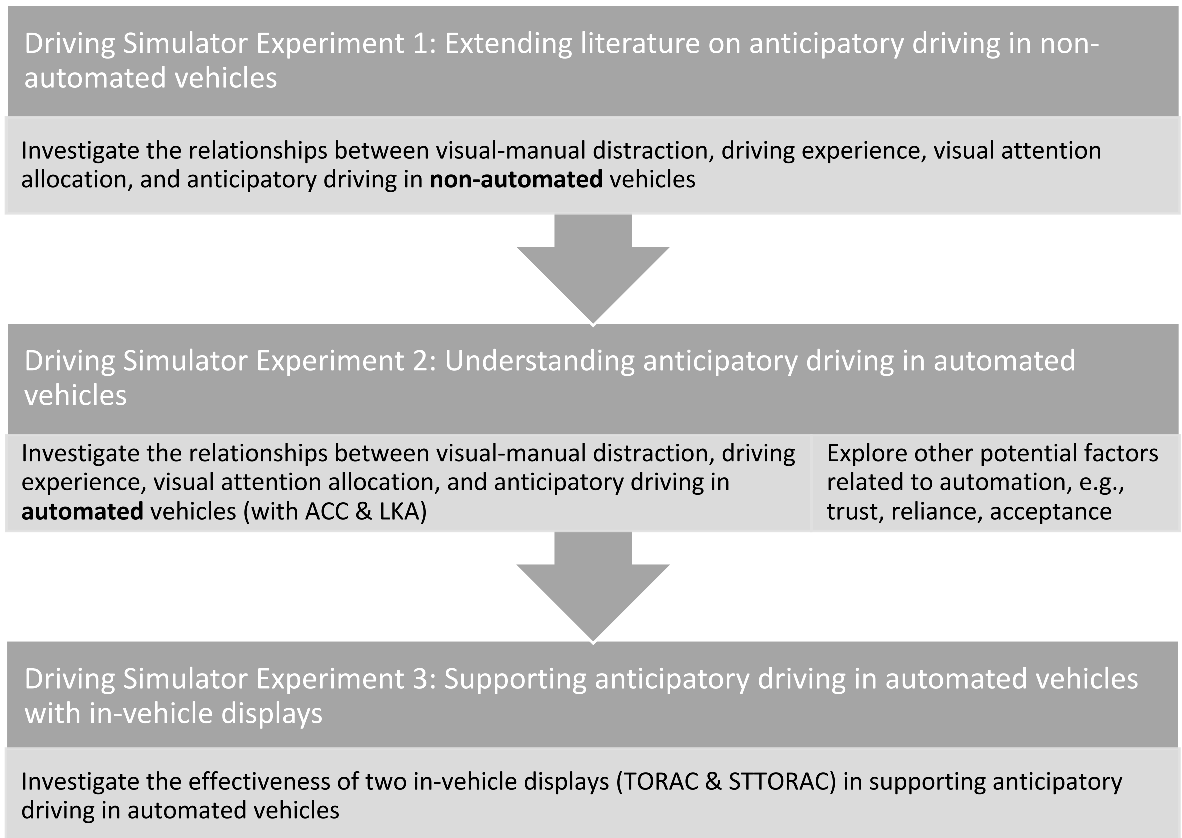


Figure 2. Experiment plans for the three driving simulator experiments

The rest of this dissertation is organized as follows. Chapter 2 introduces the apparatus, the simulated driving environments, the secondary task that was adopted as a non-driving task, and the questionnaires used in all three experiments. Chapter 3 presents the experiment design and findings of Experiment 1. Chapter 4 presents the experiment design and the findings of Experiment 2. A comparison of drivers' visual attention allocation preceding and during anticipatory driving scenarios between non-automated and automated vehicle driving is also reported in this chapter, which compares the findings of Experiments 1 and 2 (Chapter 4.5). Chapter 5 describes the experiment design, the display designs, and findings for Experiment 3. Lastly, Chapter 6 summarizes the findings in these three experiments, the contributions and implications of this dissertation, and discusses the limitations and future research directions.

Chapter 2

2 Apparatus, Participants, Simulated Driving Environment, Secondary Task and Questionnaires

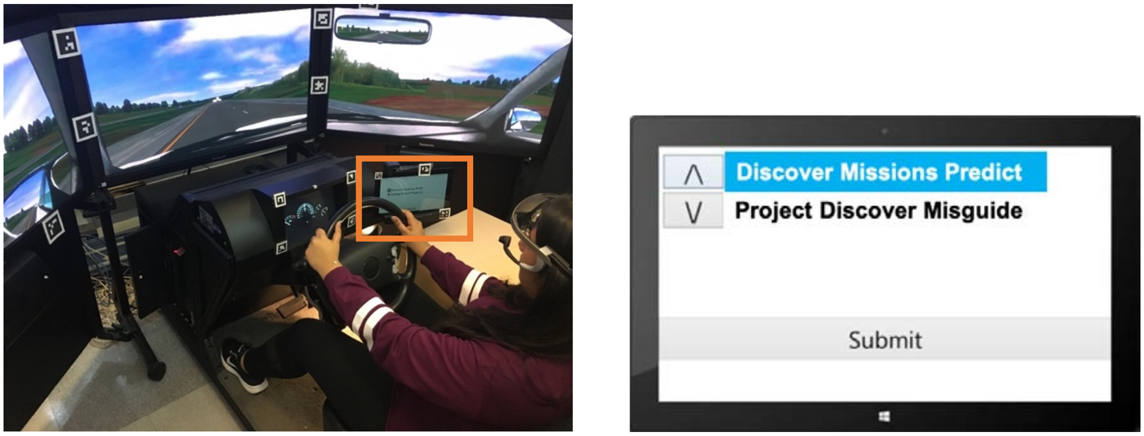
2.1 Apparatus

2.1.1 Driving simulator

The data collection for this dissertation was conducted on a NADS MiniSim Driving Simulator (Figure 3a). The NADS MiniSim™ is a PC-based quarter-cab driving simulator developed by the University of Iowa's National Advanced Driving Simulator (NADS). It is a fixed-based simulator with three 42-inch screens, creating a 130° horizontal and 24° vertical field at a 48-inch viewing distance. In addition, a 20-inch digital dashboard displays speedometer and on/off states of the automation (enabled in automated vehicles in Experiment 2 and Experiment 3). The simulator also features stereo sound produced by two satellite speakers at the front left and front right. The simulator collects a large number of measures, including driver inputs (e.g., pedal position and pedal force), vehicle information (e.g., speed and lane deviation), and scenario variables (e.g., headway of lead vehicle) at 60 Hz. The simulator also broadcasts a monotonically increasing number (called "frame number") through the ethernet port, which can be recorded by all other data recording devices (e.g., eye-tracker), so that the data collected in these devices can be synchronized with the events in the simulator.

2.1.2 In-vehicle display

A Surface Pro 2 laptop with 10.6" touchscreen (screen size of 235 mm × 132 mm) was mounted to the right of the dashboard (Figure 3a, highlighted in a rectangle) to display the secondary task in the experiments. A visual-manual non-driving task developed in Python was adopted as the secondary task in this dissertation (detailed in Chapter 2.5). Participants' manual interactions with the secondary task and the timing of the interactions were recorded automatically.



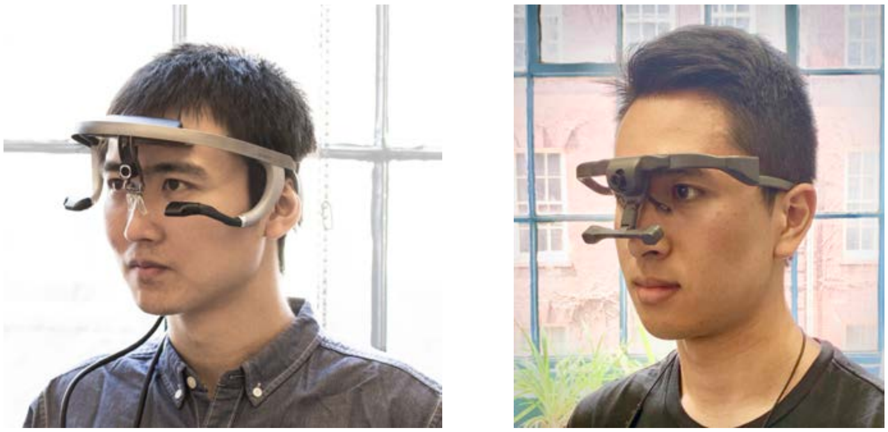
(a) (b)

Figure 3. Apparatus: (a) NADS MiniSim driving simulator with in-vehicle display highlighted; (b) Secondary task

2.1.3 Eye-tracking system & driver behavior monitoring devices

Two versions of the Dikablis head-mounted eye-tracking system by Ergoneers were used to record participants' gaze positions in the experiments. The manufacturer reported glance direction accuracies of both versions of the eye-tracking system varied between 0.1^{o} and 0.3^{o} (translating to 2 mm to 6 mm on the middle simulator screen at a viewing distance of 1.2 m), at the a sampling frequency of 60 Hz (i.e., 16.7 ms in time resolution). Two versions of the eye-tracker were used in the three experiments with slight differences between them in terms of weight and ease of calibration. Figure 4a shows the eye-tracker used in experiments 1 and 2, whereas Figure 4b shows a lighter and easier to calibrate version that was used in experiment 3 A software called "D-Lab" by Ergoneers was used to collect the eye-tracking data. The gaze position (as crosshairs, see Figure 8) was overlapped automatically on the videos (resolution of 1920 × 1080 at 30 fps) recorded through a forward scene camera attached in the middle of the eye trackers. This video was available to the experimenter during data collection and enabled confirmation of satisfactory calibration. The experimenter asked participants to fixate their gaze on four pre-specified locations on the screens and confirmed through a recorded video that the crosshairs fell on the position the participant was asked to fixate on.

Two other cameras were used to record drivers' behaviors in the experiments, and the videos were recorded in D-Lab as well. One of the cameras was mounted below the dashboard and recorded pedal movements. The other one was attached to a tripod beside the drivers' seat to record participants' body and hand movements.



(a) (b)

Figure 4. Apparatus: (a) Dikablis eye-tracker used in Experiment 1 and Experiment 2; (b) Dikablis eye tracker used in Experiment 3

2.1.4 Physiological sensors

Heart rate (HR) and galvanic skin response (GSR) were recorded in Experiment 1 and Experiment 2. They were used as workload measures (Carsten et al., 2012; Cha, 2003; He et al., 2019; He et al., 2017). Electrocardiogram (ECG, which can be used to calculate HR) and GSR (i.e., skin conductance) were recorded through sensors by Becker Meditec. The data was recorded at 240 Hz using the D-Lab software developed by Ergoneers (Figure 5a, Figure 5b, and Figure 5c). ECG was recorded with three solid gel foam electrodes placed on the participants' chest. The GSR solid gel foam electrodes were attached beneath the bare left foot with one sensor in the middle and the other under the heel. The physiological measures (including ECG and GSR) were abandoned and not recorded in Experiment 3 because no significant trends were found for these measures in Experiment 1 and Experiment 2, and thus they added no additional information to the dataset (workload was also measured through subjective questionnaires in all three experiments).

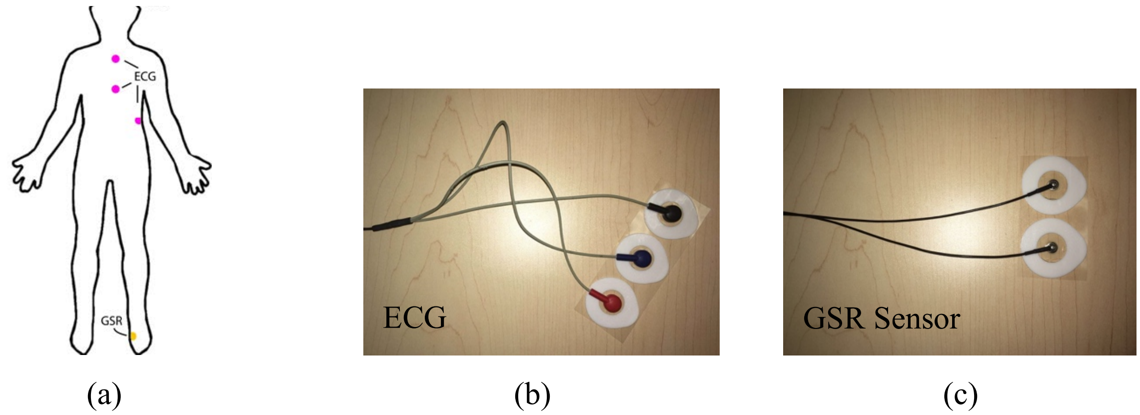


Figure 5. Apparatus: (a) Positioning of the physiological sensors; (b) ECG sensor; (c) GSR sensor

2.2 Participant profiles and compensation strategies

The participants were recruited mainly through advertisements posted on the University of Toronto campus, in online forums, and nearby residential areas (see Poster in Appendix C). The driving experience criteria were based on Stahl et al. (2016). Experienced drivers had to have a full driver's license (G in Ontario or equivalent elsewhere in Canada or the U.S.) for at least eight years with > 20,000 km driven in the past one year. Novice drivers obtained their first learners' license (G2 in Ontario or equivalent elsewhere in Canada or the U.S.) less than three years with < 10,000 km driven in the past one year. Participants were chosen based on their answers in a screening questionnaire (see Appendix D for the screening questionnaire in Experiment 1, Appendix E for the screening questionnaire in Experiment 2 & 3). It should be noted that although it was required that the participants should be able to drive without glasses for better tracking quality of the eye-tracking system, it was later found that the tracking quality was good enough even with glasses. Consequently, the participants with glasses were not filtered out.

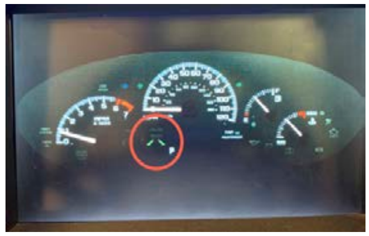
The duration of an experiment session was around 2.5 hours for each participant in all three experiments. All participants received $50 regardless of their performance. However, participants were told that they would be compensated at a rate of C$14/hr and could receive a bonus of up to $8 based on their performance. For the no secondary task conditions, this bonus was tied to driving performance only; for the secondary task conditions, it was tied to both driving and secondary task performances. Participants in the secondary task conditions were further told that they would receive \$0.20 for each correct answer and lose \$0.40 for each incorrect answer in the secondary task to encourage them to care about the secondary task in addition to the driving task, as they would do in the real world (e.g., taking a work-related phone call while driving, or searching for a favourite song on the radio).

2.3 Adaptive cruise control (ACC) & lane keeping assistance (LKA)

The automated driving system used in Experiments 2 and 3 consisted of ACC and LKA, creating an SAE level-2 automation (SAE On-Road Automated Vehicle Standards Committee, 2018). The ACC is available for many vehicles in the market and can maintain a constant cruise speed or automatically adjusts the vehicle speed to maintain a minimum gap time to the lead vehicle if the lead vehicle travels slower than the set cruise speed of the ego-vehicle. The gap time was computed as the distance from back bumper of the lead vehicle to the front bumper of the ego-vehicle divided by the speed of ego-vehicle. For most ACC systems available in the market, the minimum gap time can be customized by the users. However, to better control the consistency of the scenarios experienced by participants in the experiments, the minimum gap time was set to 2 sec, a value that is commonly recommended for highway safety (e.g., New York State Department of Motor Vehicles; Road Safety Authority in the Government of Ireland), and participants were not allowed to change it. The ACC could also not use the full braking power of the braking system or recognize stationary objects on the road. Thus, in case of emergency, drivers were still required to step in and brake manually to avoid collisions with other road agents. In the experiments, the maximum deceleration that the ACC could generate was 0.3 g.

The LKA controls the lateral dynamics of the vehicle and helps keep the vehicle in the middle of the lane. The LKA usually relies on the lane markings to detect and stay in the lane. As a result, if the lane markings are not visible, the LKA system may not be able to keep the direction of the vehicle and thus would require drivers to step in.

In both experiments, the icons on the dashboard showed whether the ACC and LKA were engaged or not (Figure 6). Additional displays showing states of the ACC and LKA were provided to the drivers in Experiment 3, which will be described in detail in Chapter 5.2.4.

(a) (b)

(c) (d)

Figure 6. The states of ACC and LKA on the dashboard: (a) LKA disengaged; (b) LKA engaged; (c) ACC and LKA engaged; (d) ACC disengaged and LKA engaged

In the NADS MiniSim driving simulator, the ACC can be controlled using three buttons on the left side of the steering wheel (Figure 7). The top one is the “RES” and “+” button; the middle one is the “CANCEL” button, and the bottom one is the “SET” and “-” button. The ACC can be engaged and set at the vehicle’s current speed by pressing the SET button, and resumed to the last cruise speed by pressing the RES button. After the ACC is engaged, the cruise speed can be increased or decreased by pressing the “+” or “-” button. Each time the buttons are pressed, the cruise speed changes by 2 mph. The ACC can be disengaged by pressing the “CANCEL” button or using the braking pedal directly. The LKA can be controlled using one button on the right side of the steering wheel (Figure 7). Drivers can engage and disengage the LKA using the button. They can also disengage the LKA by turning the steering wheel over 5^{o}.

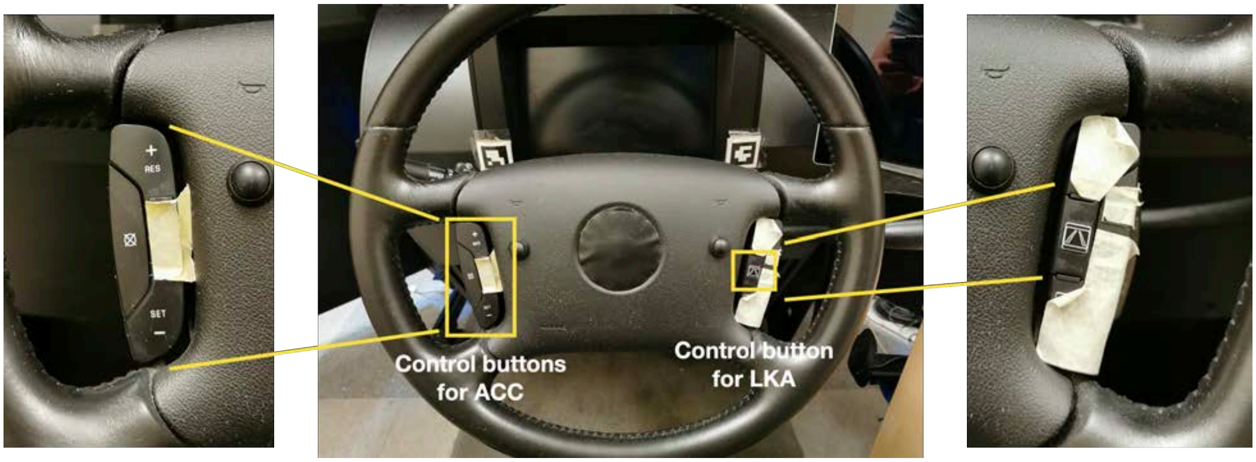


Figure 7. Control buttons for ACC and LKA on the steering wheel

2.4 Driving environment

In all three experiments, each participant completed four experimental drives, two on a 2-lane rural road (Figure 8a) with a speed limit of 80.5 km/h (50 mph) and the other two on a 4-lane highway (Figure 8b) with a speed limit of 96.6 km/h (60 mph). There was light traffic on the road but no pedestrians or traffic-light-controlled intersections. Participants were told to follow a lead vehicle and stay in their lane unless asked to turn by the experimenter.

(a)

(b)

Figure 8. Road and traffic environment of the two types of roads used in the experiments, the crosshairs show the gaze position of the driver: (a) rural road; (b) highway

2.5 Secondary task

The secondary task, "Discover Project Missions" (Donmez, Boyle, & Lee, 2007), a visual-manual task that mimics the operation of in-vehicle information systems (e.g., searching for and selecting songs), was used as the secondary task in all three experiments (Figure 3b). The task has been found to degrade driving performance in other studies (Chen, Hoekstra-Atwood, & Donmez, 2018; Merrikhpour & Donmez, 2017). The task required participants to find one matching phrase out of 10 candidate phrases. A matching phrase was one that had either "Discover" as its first word, or "Project" as its second word, or "Missions" as its third word (e.g., "Project Discover Misguide" is not a match, whereas "Discover Missions Predict" is). Only two phrases were visible on screen at any time; participants could tap up and down arrows to scroll through the ten phrases in each question. Once participants identified a matching phrase, they had to tap on it and then tap on a submit button, which was followed by visual feedback on the correctness of their choice. Then, a new set of ten phrases would be provided after participants pressed a "start" button, regardless of the correctness of the last submission. For participants assigned to a condition with the secondary task, the task was available throughout the whole drive, and they could decide when to engage in the task at their own pace.

2.6 Questionnaires used in the experiments

A variety of questionnaires were used in the experiments, as detailed below in Table 2. It should be noted that not all questionnaires were used in all experiments. The "checklist for trust between people and automation," "system acceptance questionnaire" and "complacency-potential factors" questionnaires were not used in Experiment 1 as no automated driving systems were used in this experiment. The "self-reported anticipatory driving behaviors" questionnaire was not used in Experiment 3 because no significant results were found for this questionnaire in Experiment 1 or Experiment 2.

Table 2. Descriptions of questionnaires used in the three experiments

Questionnaire	Descriptions	Used in experiment?		
		Exp. 1	Exp. 2	Exp. 3
Within-experiment questionnaires				
NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988); *see Appendix H*	It measures subjective workload in a drive and has six constructs (i.e., mental demand, physical demand, temporal demand, performance, effort, and frustration) assessed on a scale ranging from ''0: very low'' to ''100: very high.''	Yes	Yes	Yes
Risk Perception (Tsimhoni, Smith, & Green, 2003); *see Appendix I*	It measures how much risk drivers felt in a drive and consists of a 10-point ordinal scale ranging from "1: as risky as driving on an easy road with no traffic, pedestrians, or animals while perfectly alert" to "10: as risky as driving with my eyes closed, a crash is bound to occur every time I do this"	Yes	Yes	Yes
Situation Awareness Rating Technique (SART; Selcon & Taylor, 1990); *see Appendix J*	It measures the situation awareness of the drivers in a drive on three dimensions, i.e., demand, supply, and understanding, each ranging from "1: low" to "7: high"	Yes	Yes	Yes
Checklist for Trust between People and Automation (Jian, Bisantz, & Drury, 2000); *see Appendix K*	It measures drivers' attitudes toward the automated driving systems they used in a drive with seven questions, each ranging from "1: negative" and "7: positive"	No	Yes	Yes
System Acceptance Questionnaire (Van Der Laan, Heino, & De Waard, 1997); *see Appendix L*	It measures acceptance of the automated driving systems used in a drive across two dimensions, i.e., satisfaction and pleasantness, each ranging from "-2: negative" and "2: positive"	No	Yes	Yes
Post-experiment questionnaires				
Self-Reported Anticipatory Driving Behaviors *see Appendix M and Appendix N*	In this questionnaire, drivers report what they did in response to cues or events in the anticipatory scenarios. They are also asked to recall and order a list of events that happened in the anticipatory scenarios	Yes	Yes	No

Manchester Driver Behavior Questionnaire (DBQ; Lajunen, Parker, & Stradling, 1998)*; see Appendix O*	It measures self-reported aberrant driver behaviors and has three dimensions: i.e., violation, error, and lapse (ranging from 0: "Never" to 6: "Nearly all the time").	Yes	Yes	Yes
Susceptibility to Driver Distraction Questionnaire (SDDQ; Feng, Marulanda, & Donmez, 2014); *see Appendix P*	It collects data on self-reported frequency of distraction engagement while driving in daily life. It has three dimensions: i.e., distraction engagement (ranging from 1: "Never" to 5: "Very Often"), attitudes and beliefs about voluntary distraction (ranging from 1: "Strongly Disagree" to 5: "Strongly Agree"), and susceptibility to involuntary distraction (ranging from 1: "Never" to 5: "Very Often," but participants can choose "Never Happen" if they never encountered similar situations)	Yes	Yes	Yes
Demographic Information *see Appendix Q*	It collects participants' basic demographic information, including education, type of job, marriage status, household income, and city of residence. Participants can skip questions in this questionnaire in case they felt uncomfortable.	Yes	Yes	Yes
Modified Complacency-Potential Factors Modified from Singh, Molloy and Parasuraman (1993)*; see Appendix R*	It measures people's complacency toward commonly encountered automated devices in daily life (e.g., ATM), with three dimensions, i.e., confidence, reliance, and trust. It has ten questions, each ranging from 1: "strongly disagree" to 5: "strongly agree". The modification removed two questions on experience with two uncommon devices (i.e., searching for books in the library by manually sorting through a card catalogue and taping TV programs manually on a VCR) that would be rarely used nowadays.	No	Yes	Yes

Chapter 3

3 Driving Simulator Experiment 1: Understanding the Effect of Driving Experience and Distraction on Anticipatory Driving in Non-Automated Vehicles

3.1 Introduction

This section presents the results of the first driving simulator experiment (Experiment 1), which aimed to investigate the influence of visual-manual distractions on anticipatory driving behaviors of both novice and experienced drivers. The experiment was approved by the Research Ethics Board of the University of Toronto, with a protocol number #34679. A self-paced secondary task paradigm was used to enable the drivers to moderate their distraction engagement based on their anticipation of how traffic can evolve (see Chapter 2.5). Drivers' anticipatory actions across multiple scenarios, their engagement with the secondary task, and their glances toward anticipatory cues were analyzed. All glance data was analyzed using the ISO 15007-1:2014(E) standard (International Organization for Standardization, 2014). Glance behaviors were analyzed while considering the temporal development of the traffic scenarios (by looking at time series of glance behaviors and comparing driver glance behaviors before and after the onset of anticipatory cues). The relation between anticipatory actions and glance metrics was also investigated. The results from this experiment have been published as a journal article in *Human Factors: The Journal of the Human Factors and Ergonomics Society* (He & Donmez, 2020) and a conference proceeding article in *Human Factors and Ergonomics Society 62nd Annual Meeting* (He & Donmez, 2018).

3.2 Method

3.2.1 Experiment design

The experiment had a 2 × 2 between-subjects design (Table 3), with 4 male and 4 female participants in each of the four conditions, resulting in 32 participants in total. The between-subjects experiment design was adopted in order to minimize learning and fatigue effects and to not repeat the same scenarios multiple times for a given participant. The independent variables were driving experience (novice vs. experienced) and secondary task availability (with vs. without). Driving experience was defined based on Stahl et al. (2016). Each participant completed four scenarios in the simulator, with each scenario involving several traffic cues designed to allow the anticipation of an event.

Table 3. Experimental design and participant age in Experiment 1

Group: Participant #	Secondary Task	Experience	Mean Age (Min - Max, SD)		
			Grand Total	**Male**	**Female**
1: #1-8	With	Novice	21.8 (19 - 27, 2.9)	21 (19 - 23, 1.6)	22.5 (19 - 27, 3.6)
2: #9-16		Experienced	30.3 (25 - 36, 3.9)	31 (27 - 35, 2.8)	29 (25 - 36, 5.0)
3: #17-24	Without	Novice	25.3 (19 - 33, 5.2)	26.5 (21 - 33, 4.3)	24 (19 - 33, 5.7)
4: #25-32		Experienced	33.9 (26 - 47, 7.1)	32.5 (29 - 39, 3.9)	35.3 (26 - 47, 9.0)

3.2.2 Participants

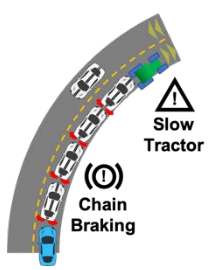
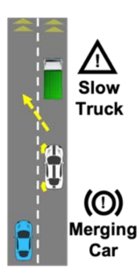
The 32 participants who completed the study were mainly recruited through advertisements posted in online forums, on the university campus, and in nearby residential areas. The recruitment criteria were based on driving experience, as described in Chapter 2.2. Participants' experience with automation (i.e., ACC or LKA) was not collected in this experiment. The sample size in this experiment was limited by the time and economic constraints of the study, but is comparable to relevant studies, which focused on anticipatory driving in general (e.g., Stahl et al., 2014, 2016) and hazard anticipation in particular (e.g., Borowsky et al., 2015; Horberry et al., 2006). As expected, novice drivers were generally younger than experienced ones, $t(30)=4.4$, $p=.0001$. The average age of the experienced drivers was 32.1 (standard deviation (SD)=6.2) whereas the average age for the novice drivers was 23.5 (SD=4.7). As desired, no age differences were found across secondary task levels within novice drivers, $t(14)=1.55$, $p=.14$, or within experienced drivers, $t(14)=1.19$, $p=.26$. Informed consent was obtained from each participant.

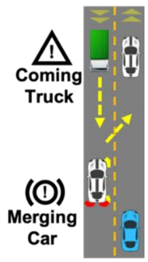
3.2.3 Driving task & secondary task

Each participant completed four experimental drives (~5 minutes each), each with one scenario designed to capture anticipatory driving. These scenarios were adopted from our group's earlier work (Stahl et al., 2014, 2016, 2019) and are visualized in Table 4. Scenarios 1 and 3 were on rural roads (speed limit 50 mph), and 2 and 4 were on highways (speed limit 60 mph).

Participants were instructed to drive around the speed limit, follow lead vehicles, and prioritize driving safety. Scenario order was kept constant across participants given that it was not possible to fully counterbalance the scenario order across the number of participants recruited for this experiment: a potential limitation of the study. In these four scenarios, the beginning of an event (i.e., event onset) was marked by an action of a lead or overtaking vehicle that would unambiguously indicate the upcoming event that the participant had to react to, for example, a directional signal of a vehicle indicating the beginning of its intended lane change. In contrast, pre-event or anticipatory cues could indicate an event but with less certainty (e.g., the decreasing distance between two vehicles suggests that the following vehicle may change lanes; however, the following vehicle may also choose to slow down instead of changing lanes). Detailed scenario descriptions are provided as follows in Table 4. Example images of participants attending to the anticipatory cues are shown in Figure 9. The reader can refer to Section 2.5 for the details of the visual-manual secondary task implemented in this experiment.

Table 4. Description of anticipatory driving scenarios used in Experiment 1

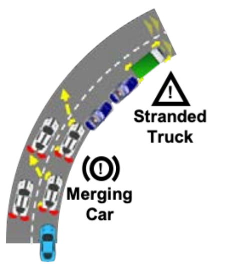
Scenario Image	Scenario Description
	<u>*Chain Braking Event Due to Slow Tractor (Scenario 1)*</u> Ego-vehicle followed a chain of four vehicles on a two-lane rural road with moderate oncoming traffic, traveling at 80.5 km/h (50 mph). Due to a slow tractor ahead on a curve, traveling at 40.2 km/h (25 mph), the front-most vehicle started to brake when within 22 m of the tractor, with a deceleration of 8 m/s^2. The other lead vehicles braked consecutively. • <u>*Anticipatory cues*</u>: slow tractor, reducing distance between lead vehicles, braking of lead vehicles (except the one directly ahead) • <u>*Event onset*</u>: braking of vehicle directly ahead
	<u>*Merging Event Due to Slow Truck (Scenario 2)*</u> Ego-vehicle traveled at 96.6 km/h in the left lane while driving on a four-lane divided highway. The ego-vehicle approached a truck and a following vehicle on the right lane, initially traveling at 72.4 km/h (45 mph). As the distance between the truck and the ego-vehicle fall under 210 m, the truck slowed down to be 64.7 km/h (40 mph). After about 11 s, the following vehicle (behind the truck) signaled left for 2 seconds, and then accelerated to be 80.5 km/h at a rate of 4.9 m/s^2 and merged into participant's lane, trying to pass the truck. • <u>*Anticipatory cues*</u>: reducing distance between the truck and the following vehicle • <u>*Event onset*</u>: left signal of the following vehicle



<u>Merging Event Due to Coming Truck *(Scenario 3)*</u>

The ego-vehicle followed a lead vehicle on a rural road. On a straight road, the vehicle directly behind the ego-vehicle (overtaking vehicle) signaled left for 2 seconds with high beams, pulled into the opposite lane, and accelerated to be 7.2 km/h (4.5 mph) faster than the ego-vehicle to overtake the ego-vehicle. Because of an coming truck, the overtaking vehicle had to cut in front of the ego-vehicle abruptly after signaling right for 2 seconds.

- *<u>Anticipatory cues</u>*: the left signal and left merging of the overtaking vehicle, emerging of the coming truck
- *<u>Event onset</u>*: right signal of the overtaking vehicle

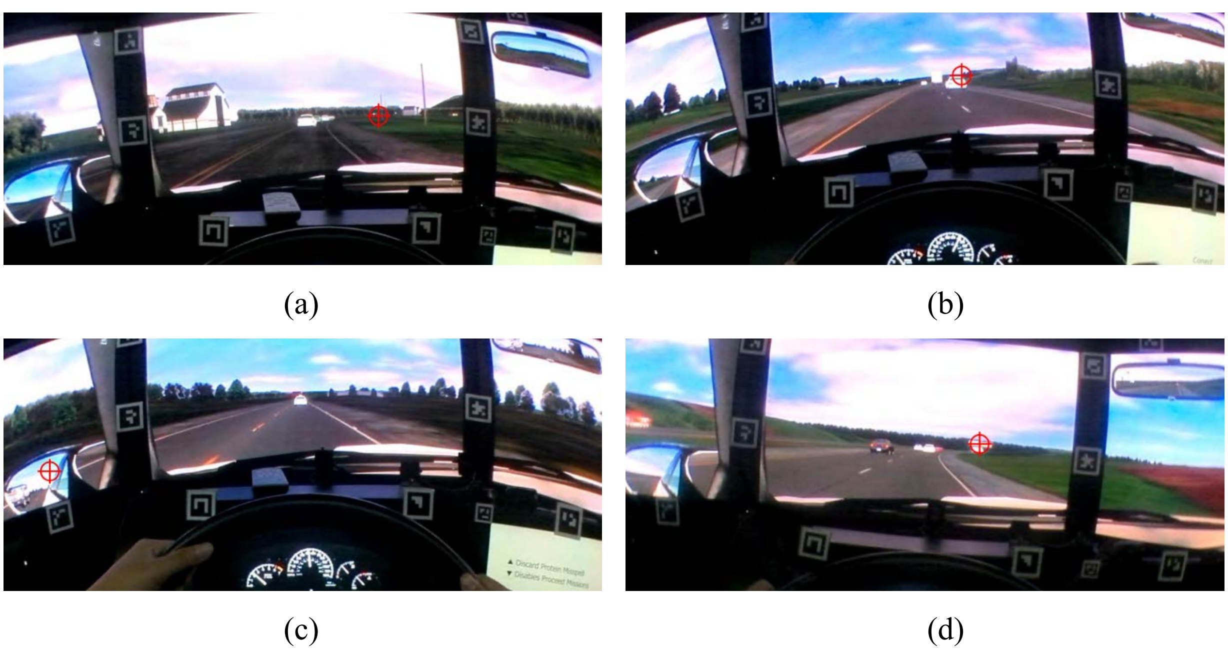


<u>Chain Braking Event Due to Stranded Truck (Scenario 4)</u>

The ego-vehicle was driving in the right lane of a four-lane highway. Because of a stranded truck with two police cars behind, two lead vehicles in front of the ego-vehicle were forced to brake with a deceleration of 5m/s^2, and merged left after signaling left for 2 seconds. The cars in the left lane also braked to make room for merging vehicles with deceleration rates of 5 m/s^2.

- *<u>Anticipatory cues</u>*: the truck and the police vehicles becoming visible
- *<u>Event onset</u>*: braking of the vehicle directly ahead

***Note*:** In the figures, the blue vehicle at the bottom of each image represents the ego-vehicle, travelling in the 'upward' direction; the green vehicles at the top are trucks or tractors; other vehicles are white except the police cars in Scenario 4. By default, all vehicles travel forward in the sketches. The yellow dash arrows indicate potential paths of the road agents.



(a) (b) (c) (d)

Figure 9. Images from eye-tracking videos for the four scenarios. In each image, the participant's gaze (indicated by crosshairs) is on an anticipatory cue. The crosshairs are on: (a) Scenario 1: the tractor; (b) Scenario 2: the slow-moving vehicle ahead; (c) Scenario 3: the left-mirror image of the vehicle trying to overtake the participant; (4) Scenario 4: the stranded truck and the police vehicles

3.2.4 Procedure

Participants completed an acclimation drive on a route similar in terms of traffic density and road type (i.e., they drove from rural road to highway) to the routes used in the experiment. This drive lasted at least 5 minutes and continued until participants indicated that they were comfortable driving in the simulator. Participants who were in the secondary task condition were then introduced to the secondary task; they then practiced the task, first without, and then while driving. All participants completed one more practice drive before they started the experimental drives. This practice drive involved two braking events but no anticipatory scenarios. The participants were told that this was an experimental drive in order to minimize their ability to deduce the purpose of the experiment. In the last practice drive and all experimental drives, participants were told to drive around the speed limit, do not pass or fall too much behind the lead vehicle, and keep driving on either the left or the right lane, unless it was necessary to change lanes (see Appendix S for detailed instructions). Participants then completed the four experimental drives. The eye-tracker was calibrated in the beginning of the experiment and was re-calibrated before each drive.

3.2.5 Dependent variables of anticipation and secondary task engagement

*Exhibition of a Pre-*event *Action*. Three raters (including the author of this dissertation), who were blind to the driving experience of the participants, used eye-tracking videos and videos of participants' feet, along with driving data (i.e., speed, pedal position) to independently categorize whether a participant clearly exhibited a pre-event action (i.e., acted prior to the event onset), or whether no clear pre-event action could be identified. Two raters had 8 years of driving experience while the other had 3 years of driving experience when they judged the experiment. Pre-event actions consisted of slowing down by releasing the gas pedal or by pressing the brake pedal (all scenarios), speeding up by pressing the gas pedal (scenarios 2 and 3), and moving to the left lane (scenario 4). At least one glance toward an anticipatory cue was required prior to an action for it to be categorized as a pre-event action. This strategy reduced the risk that an irrelevant acceleration or deceleration was regarded as a pre-event action. Although the raters were not provided with strict criteria about what constituted a clear pre-event action, they were trained on the concept of anticipatory driving and what potential pre-event actions were in each scenario, and were instructed to exclude cases where the participant appeared to release or press a pedal to maintain speed. This subjectivity involved in identifying a pre-event action was the reason for us to utilize three independent raters blind to the experimental conditions. A substantial agreement level was reached across the raters before they discussed their categorizations, Fleiss' $\kappa=0.6$, $z=11.84$, $p<.05$ (Fleiss, 1971). Conflicts were then resolved through discussions.

Glance Behaviors. Glance metrics (Table 5) were extracted according to ISO 15007-1:2014(E) (International Organization for Standardization, 2014) and by reviewing eye-tracking videos. A glance was defined from the moment at which the direction of gaze started to move toward an area of interest (AOI) to the moment it started to move away from the AOI (as per Figure A.2 in ISO 15007-1:2014(E)). Glances shorter than 100 ms were excluded from analysis (Crundall & Underwood, 2011; Horrey & Wickens, 2007). The AOIs analyzed included the anticipatory cues, the road (including mirrors), and the secondary task display. A cue was considered to be visible to the drivers when its height was at least 10 mm on the screen (~0.5° visual angle), a threshold identified in pilot testing. Given that some glances could partially fall on a data extraction period of interest (e.g., from the first cue becoming visible to event onset), the number of glances over a period of interest utilized portions following the method in Seppelt et al. (2017) (e.g., if 0.7 seconds of a 1 second glance fell on the period of interest, then this glance was counted as 0.7 glances). Percent time looking at an AOI was calculated as the total time spent on an AOI within the data extraction period of interest divided by the length of the data extraction period. The mean glance duration was calculated as the total time spent on an AOI divided by the number of glances in the data extraction period. If a participant never looked at an AOI in the data extraction period, the mean glance duration was assigned to be zero. Further, if a participant never looked at an anticipatory cue before the event onset, their time until first glance to an anticipatory cue was considered to be the entire data extraction period (from first cue becoming visible to event onset). AttenD, a composite metric combining both on-road and off-road glances developed by Kircher and Ahlström (2009) was also extracted; AttenD ranges from 0 (less attention to the road) to 2 (more attention to the road).

Table 5. Glance behavior metrics used in Experiment 1 for each area of interest, and relevant findings in previous research

Period of Analysis	Areas of Interest	Metric	Relevant Findings from Naturalistic Driving Studies, Unless Otherwise Noted
From cue onset to event onset	*Anticipatory Cues*	Mean glance duration (ms) Percent of time looking (%) Rate of glances (/min)	- In a recent work, it was found that experienced drivers have more and longer glances on anticipatory cues compared to novices in a simulator study (Stahl et al., 2019). - In an instrumented vehicle study with eye tracking, it was found that inexperienced drivers had higher number of fixations on potential hazards, however, experienced drivers were better able to adapt their number of fixations based on type of road (Falkmer & Gregersen, 2005).
		Time until first glance (ms)	No effect of experience was found on time until first fixation on a potential hazard when a static traffic image was presented to the participants (Huestegge et al., 2010).
From 20 seconds before cue onset to event onset	*Secondary Task Display*	Mean glance duration (ms)	- Mean off-path glance duration in a 12-s time window is larger preceding safety-critical events than it is for non-safety-critical periods (Victor et al., 2015). - Distraction algorithms that incorporate the current off-path glance duration are the most sensitive to assess crash risk (Liang, Lee, & Yekhshatyan, 2012).
		Percent of time looking (%)	- Percent off-path glance time in a 2-s time window is larger preceding safety-critical events than it is for non-safety-critical periods (Victor et al., 2015). - For commercial vehicle operators, total duration of eyes-off forward roadway in a 6-s period is larger preceding a safety-critical event than it is in non-safety critical periods (Olson et al., 2009).
		Rate of glances (/min)	For commercial vehicle operators, number of off-path glances in a 6-s period is larger preceding a safety-critical event than it is in non-safety-critical periods (Olson et al., 2009).
		Existence of long (>2 s) glances	Glances away from forward roadway (off-path glances) longer than 2 s double the risk of safety-critical events (Klauer et al., 2006; Victor et al., 2015).
	Road	Mean glance duration (ms)	- Mean on-road glance duration is shorter preceding a crash event compared to a near-crash event (Seppelt et al., 2017). - In a simulator study, it was found that when drivers were allowed to look at the road for 4 s compared to shorter durations, they had more chances of fixating on a potential hazard (Samuel & Fisher, 2015).
		Percent of time looking (%)	Percent of on-road glance time is shorter preceding a crash event compared to a near-crash event (Seppelt et al., 2017).
	Secondary Task Display, Road, and Dashboard	Average AttenD	AttenD differentiates safety-critical events from non-safety-critical periods (Seppelt et al., 2017).

Table 5 presents relevant findings mainly from naturalistic driving studies, connecting glance metrics to crash risk. It should be noted that the resolution provided by naturalistic driving data to identify glance location is limited; therefore, almost all studies cited in Table 5 focused on on-path vs. off-path glances. However, eye-tracking data from this study provides rich information regarding gaze location and hence the analyses in this chapter went beyond the dichotomy of on-path/off-path glances, and described glance behavior in more detail such as by focusing on the secondary task display as well as anticipatory cues. The metrics on anticipatory cues in this study are particularly novel as previous hazard anticipation studies looked at whether a glance was made on a hazard or on an area relevant to potential hazards, i.e., a binary response, rather than how much drivers focused on relevant cues, e.g., Fisher et al. (2017). Still, further research is needed to connect these detailed metrics to crash risk.

3.2.6 Statistical models

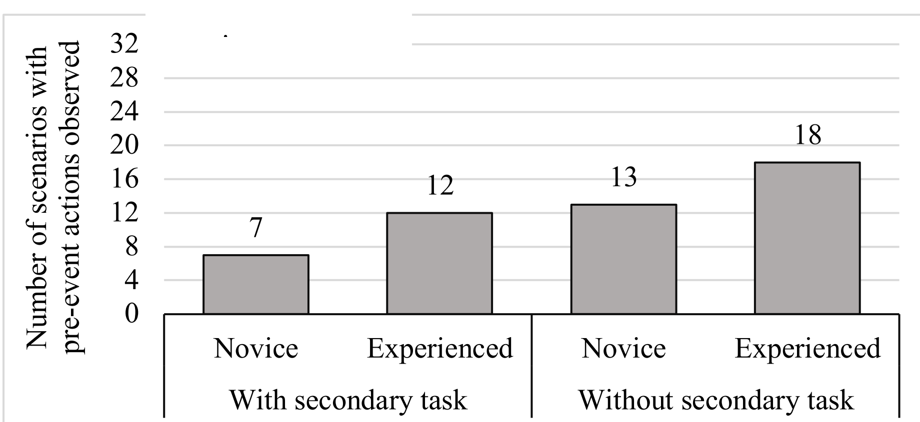
All models were built in SAS University Edition (v9.4). The two binary variables (i.e., the exhibition of a pre-event action and the existence of long glances to the secondary task) were analyzed in logistic regression models. All rate variables (i.e., rates of glances toward the road, the secondary task, and anticipatory cues) were analyzed through negative binomial regression; the length of data extraction period was used as the offset variable. Generalized estimating equations were used to handle repeated measures for both logistic and negative binomial models (i.e., 4 scenarios repeated by each participant). All other variables, except average AttenD, were analyzed using repeated measures ANOVAs, through Proc GLM in SAS with participant introduced as a random factor. Transformations were applied to some of the dependent variables to meet ANOVA assumptions; however, average AttenD was highly non-normal, and transformations failed; therefore, it was analyzed with Kruskal-Wallis tests separately for each scenario. Effects sizes are reported through 95% confidence intervals (CIs) for logistic regression and negative binomial models, and the partial omega squared (ω_p^2) (Keren & Lewis, 1979) for ANOVAs.

In addition to the independent variables that were part of the experimental design (i.e., experience and secondary task availability), one more independent variable, “cue-onset”, was created to investigate whether drivers' glance behavior changed as cues became visible. The "cue-onset" variable had two levels: before-cue-onset and after-cue-onset. Before-cue-onset period corresponded to the period from 20 seconds prior to cue onset to cue onset, the after-cue-onset period corresponded to the period from cue onset to event onset. Not all independent variables were applicable to every model. For example, rate of glances to the secondary task used data only from secondary task drives; hence the secondary task availability variable was not relevant to the analysis. Cue-onset was not used in the analysis of long glances, given that before-cue-onset and after-cue-onset periods had different lengths and it would not have been fair to compare the likelihood of long glances across these two different time periods.

3.3 Results

3.3.1 Exhibition of a pre-event action

The number of scenarios where a pre-event action was observed (Figure 10) was larger for experienced drivers, $\chi^2(1)=5.54$, $p=.02$, and when there was no secondary task, $\chi^2(1)=3.92$, $p=.048$. The odds of exhibiting a pre-event action for experienced drivers was 2.29 times the odds of exhibiting a pre-event action for novice drivers; that is, the odds ratio (OR) was 2.29, 95% CI: 1.15, 4.56. The odds of exhibiting a pre-event action with the secondary task was half of that with no secondary task, OR: 0.50, 95% CI: 0.25, 0.99. The interaction was not significant, p=.9.

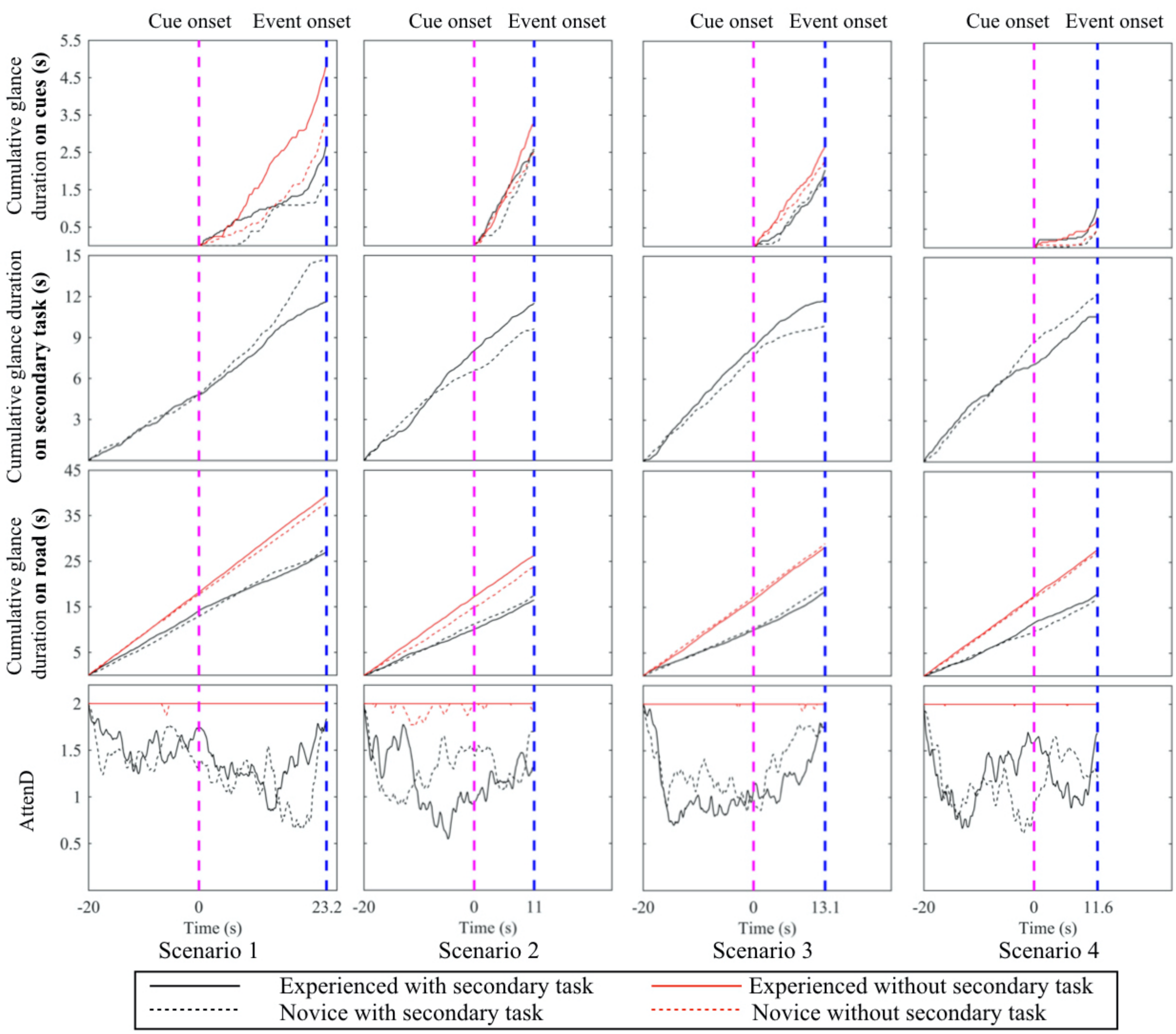


Note: the maximum possible was 32 for each condition (4 scenarios per driver for 8 drivers per condition). Each bar represents the number of scenarios where pre-event actions were observed under each experimental condition.

Figure 10. Number of scenarios where a pre-event action was observed across the four experimental conditions in Experiment 1

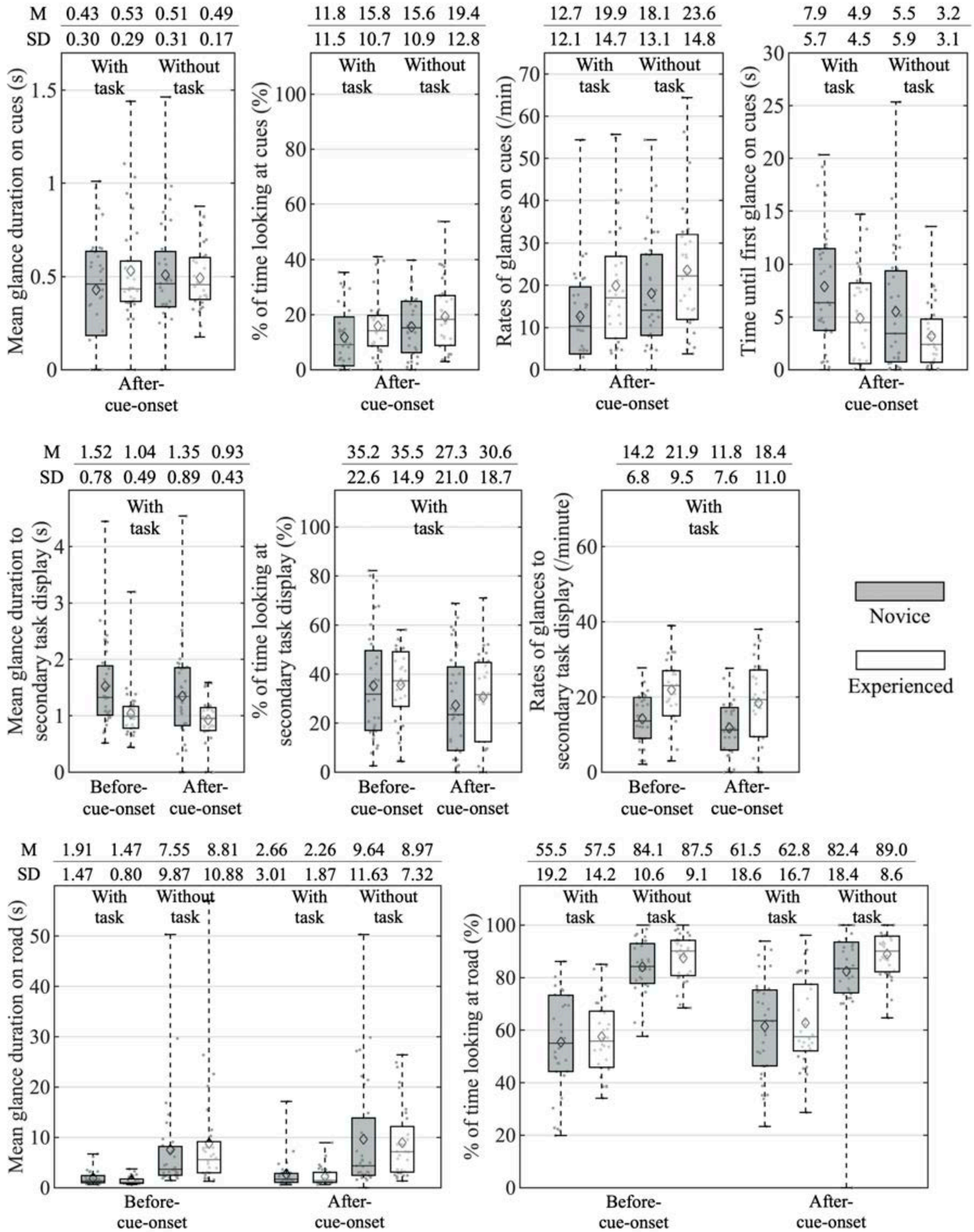
3.3.2 Glance behaviors

Figure 11 presents a temporal overview of glance behaviors for the four scenarios, averaged across the eight participants that completed each experimental condition. In particular, cumulative glance durations and AttenD over the period from 20 seconds before cue onset to event onset are presented. As can be seen from the figure, the after-cue-onset period varied based on the scenario with the averages indicated on the x-axes (e.g., 23.2 s for Scenario 1). Boxplots for glance metrics with descriptive statistics are presented in Figure 12.



Note: The vertical dash lines represent cue onset in purple and event onset in blue.

Figure 11. Temporal overview of glances from 20 s before cue onset to event onset in Experiment 1: cumulative glance durations on different AOIs and the AttenD averaged across participants



Note: In this figure and the following figures in this dissertation, boxplots present the minimum, 1st quartile, median, 3rd quartile, and maximum, along with the mean depicted through a hollow diamond. Raw data is presented with grey dots and the means are indicated with hollow diamonds. Mean (M) and standard deviation (SD) values provided at the top of each graph.

Figure 12. Boxplots of glance metrics in Experiment 1

As can be seen in Figure 11 there does not seem to be a clear separation between novice and experienced drivers in terms of their cumulative glance durations on the road or on the secondary task before cue onset. However, experienced drivers appear to have spent more time looking at cues, in particular earlier after cue onset, whereas novice drivers appear to have looked at the cues more as event onset approached. Overall, the cumulative-glance-duration-on-cues curves for experienced drivers are almost always above those for novice drivers, suggesting that experienced drivers have spent more time on cues than novices for all four scenarios. In addition to this consistency across four scenarios, Figure 11 also reveals some scenario differences. For example, experienced drivers appear to have spent less time on the secondary task after cue onset for Scenarios 1 and 4 than novices (as indicated by slope differences); whereas novice drivers appear to have spent less time on the secondary task after cue onset for Scenarios 2 and 3 than experienced drivers. There does not seem to be a difference in on-road glances across experienced and novice drivers. However, as expected, less time is spent looking on-road in the secondary task condition compared to the no secondary task condition. AttenD also reveals this expected trend; however, there are no other emergent trends in the AttenD graphs. Overall, the graphs in Figure 11 highlight the importance of detailed glance analysis – rather than just capturing at an aggregate level of whether drivers are looking on the road or not, it is also necessary to assess where they are looking on the road. The following sections present inferential statistics supporting this assessment; the significant effects are reported ($p<.05$).

3.3.2.1 On Anticipatory Cues

Compared to novices, experienced drivers spent a larger percentage of time on cues, $F(1, 28.6)=8.18$, $p=.008$, $\omega_p^2 = 0.029$, their glance rates toward anticipatory cues were 1.46 times that of the novices, $\chi^2(1)=22.02$, $p<.0001$, 95% CI: 1.25, 1.71, and they had shorter times until first glance to anticipatory cues, $F(1, 28.4)=7.98$, $p=.009$, $\omega_p^2 = 0.044$. The secondary task condition induced a generally negative effect on attention to anticipatory cues, with a decrease in percentage of time spent looking at the cues, $F(1, 28.6)=6.90$, $p=.01$, $\omega_p^2 = 0.023$, and delayed times until first glance to cues, $F(1, 28.4)=5.79$, $p=.02$, $\omega_p^2 = 0.030$, and a 23% reduction in glance rates toward cues compared to the no secondary task condition, $\chi^2(1)=10.20$, $p=.001$, 95% CI: 8, 34.

3.3.2.2 On Secondary Task Display

Experienced drivers' glance rates toward the secondary task display were 1.52 times that of the novices, $\chi^2(1)=10.99$, p=.0009, 95% CI: 1.19, 1.94, whereas novices had 6.27 times the odds of exhibiting long glances (>2 seconds) toward the display, $\chi^2(1)=5.59$, p=.02, 95% CI: 1.37, 28.75. Percentage of time looking at, F(1, 106)=4.95, p=.03, $\omega_p^2 = 0.031$, and the mean glance duration on the secondary task, F(1, 106)=4.66, p=.03, $\omega_p^2 = 0.029$, reduced after cue onset for both novice and experienced drivers.

3.3.2.3 On Road

Mean on-road glance duration, F(1,28.1)=29.23, p<.0001, $\omega_p^2 = 0.369$, and percent time spent looking on road, F(1,28.1)=70.23, p<.0001, $\omega_p^2 = 0.509$, were shorter with the secondary task for both novice and experienced drivers.

3.3.2.4 AttenD

For average AttenD, the only significant effect found was for secondary task. Average AttenD was higher in no secondary task conditions than it was in secondary task conditions, p<.05.

3.3.3 Relation between glances and exhibition of a pre-event action

The relation between pre-event actions and glance behaviors was analyzed by comparing glance metrics when there was a pre-event action and where there was none (Table 6 provides descriptive statistics for significant differences). For cue metrics, only data where there was at least one glance toward an anticipatory cue was focused on, as this was part of the criteria for identifying a response as a pre-event action; including all data would have introduced a bias in the analysis of glances on cues. In drives where a pre-event action was exhibited, drivers had longer mean glance duration on the cues, F(1, 82)=6.23, p=.01, $\omega_p^2 = 0.044$. Drives with pre-event actions also had longer mean on-road glance duration, F(1, 215)=19.27, p<.0001, $\omega_p^2 = 0.068$, and higher percentage of time looking at the road, F(1, 215)=7.02, p=.009, $\omega_p^2 = 0.024$. For on-road glance metrics, no significant interaction effects were found between cue-onset and the exhibition of a pre-event action, p>.05. Further, no significant effects were found for glances toward the secondary task, p>.05.

Table 6. Descriptive statistics for significant glance metrics for the comparison of drives with and without pre-event actions in Experiment 1

	Drives with pre-event actions Mean (SD)		**Drives without pre-event actions** Mean (SD)	
Glance metrics	*Before-cue-onset*	*After-cue-onset*	*Before-cue-onset*	*After-cue-onset*
mean glance duration on cues (s)	-	0.58 (0.23)	-	0.50 (0.24)
mean glance duration on road (s)	7.54 (11.48)	8.28 (10.29)	3.26 (3.71)	4.3 (5.08)
% of time looking at road	76.5 (19.0)	78.5 (20.0)	67.8 (20.3)	71.0 (19.5)

As reported in Table 5, Samuel and Fisher (2015) found that on-road glance duration plays a role in hazard perception. Whether this held true was assessed with the dataset from this experiment, in particular if mean on-road glance duration after cue onset predicted whether a pre-event action was exhibited for a given scenario. Further, whether mean glance duration on cues provided additional predictive power was also investigated. This analysis again focused on data where there was at least one glance toward an anticipatory cue, as this was part of the criteria for identifying a response as a pre-event action. Mean on-road glance duration from cue onset to event onset significantly predicted whether a pre-event action was exhibited, with a positive relation between the two, $\chi^2(1)=8.43$, $p=.004$: a 1 second increase in mean on-road glance duration was associated with a 7% increase in the odds of exhibiting pre-event actions, 95% CI: 2, 12. When the model also included mean glance duration on cues, $\chi^2(1)=6.35$, $p=.01$, in addition to mean glance duration on road, $\chi^2(1)=6.60$, $p=.01$, the fit statistics indicated a better fitting model (QIC decreased from 153.75 to 151.80) (Pan, 2001). In this new model, a 1 second increase in mean on-road glance duration was again associated with a 7% increase in the odds of exhibiting pre-event actions, 95% CI: 2, 13; while a 1 second increase in mean glance duration on cues was associated with a 360% increase in the odds of exhibiting pre-event actions, 95% CI: 40, 1411. Controlling for mean on-road glance duration, mean duration on cues provided additional information to predict pre-event actions; with a positive relation between mean duration on cues and pre-event actions.

3.4 Discussion

A driving simulator study was conducted to investigate the effects of visual-manual secondary tasks on drivers' anticipatory (or pre-event) actions and relevant glance behaviors for both experienced and novice drivers. Compared to earlier research on hazard anticipation (e.g., Crundall et al., 2012; Lee et al., 2008), more complex scenarios were used in this study, where the action of a traffic agent depended on and could be anticipated based on the actions of other traffic agents. Similar to earlier findings in our lab utilizing the same approach (Stahl et al., 2014, 2016, 2019), experienced drivers were found to exhibit more pre-event actions compared to novice drivers, and to have more glances toward traffic cues that facilitate the anticipation of upcoming events (i.e., anticipatory cues). It was further found that compared to novices, experienced drivers took significantly less time to first glance at anticipatory cues and spent a higher percentage of time looking at the cues. In general, the increased visual attention to cues was coupled with increased pre-event actions – a finding in line with the hazard anticipation study of Muttart et al. (2014) focusing on environmental prediction hazards. The results also showed that when drivers are engaged in a self-paced visual-manual secondary task, they are less likely to exhibit pre-event actions. Regardless of their driving experience level, drivers who were in the secondary task condition exhibited fewer pre-event actions, took longer to first glance at anticipatory cues, had lower glance rates toward the cues, and spent less time looking at the cues. Experienced drivers however had higher rates of glances toward the secondary task but were less likely to have such glances that were long (>2 seconds) compared to novices.

To better understand how drivers modulate their secondary task engagement behaviors as they anticipate a potential change in traffic, their glances on the secondary task display before and after anticipatory cues became visible were compared. It was found that drivers spent less time looking at the secondary task after cue onset, a finding in line with previous research which found drivers to reduce their secondary task engagement based on roadway demands (Schömig & Metz, 2013). Previous research also found experienced drivers to be better at adapting their in-vehicle glances according to roadway demands (Wikman et al., 1998); thus, an interaction effect was expected, with experienced drivers reducing their secondary task engagement more than novices after cue onset. However, no such effect was observed; given the relatively small sample size in this study, lack of power may have played a role here. It is also possible that unobserved factors (e.g., mind wandering) may have also played a role here; in particular, a relatively large variability in glance metrics of novice drivers was observed in this study. It was found that experienced drivers were in general better at dividing their attention between the road and the secondary task, given that they had fewer long off-road glances and paid more attention to the cues. Experienced drivers were also more likely to have pre-event actions compared to novices. Although both groups were less likely to exhibit pre-event actions when distracted, experienced drivers still performed better than novices when it came to anticipating traffic, which was likely due to their skill in “knowing where to look”.

Glance behaviors across drives with and without pre-event actions were also compared as not all experienced drivers have to be anticipatory and not all novice drivers have to lack this skill. On-road glances and glances on the cues showed significant effects, whereas glances to the secondary task did not. Similar to Samuel and Fisher (2015), it was found that on-road glance duration plays a role in anticipation. In particular it was found that mean on-road glance duration is a significant predictor of pre-event actions, but so is mean glance duration on cues. And when combined with mean on-road glance duration, mean glance duration on cues provides further predictive power.

Although this study provides unique insights into anticipatory driving, it has limitations. This study focused on a visual-manual task, but other distraction modalities are also common and have to be studied in relation to their disruptiveness to anticipation. Prior research on hazard perception has found that cognitive load experienced by drivers after a cell-phone conversation can degrade their responses to hazards (Savage, Potter, & Tatler, 2013). The analyses in this chapter did not assess such carry-over effects that might be significant. Further, the scenarios used in the experiment were adopted from earlier research from our lab and thus facilitate comparisons to the earlier findings; however, they represent only a select few situations. In addition, the method used in the experiment to study anticipation excludes the anticipatory but reactive driver, who anticipates but does not act in a proactive manner. Further research is needed to investigate and potentially catalogue different anticipation behaviors. It should also be noted that experience and age are inherently confounded in the driving population, and thus the experienced participants in this experiment were slightly older than the novice participants. Due to the age differences in the experience categories, the findings in this chapter cannot be solely attributed to experience. In the study, age was not strictly controlled when recruiting the participants within the different experience groups because the sample needed to be representative of the inherent confounds that are present in the driving population, so that there could be practically-relevant results.

Previous research has shown that in-vehicle displays can support novice drivers in exhibiting more pre-event actions (Stahl et al., 2016). The findings in this chapter suggest that novice drivers and to a lesser extent experienced drivers need further support, in particular in the presence of distractions. Based on the sample in the experiment, these conclusions apply to Canadian drivers but may also extend to other nationalities. Future research should investigate interventions, such as training and in-vehicle displays, aimed to support anticipation in the presence of distractions. For example, an in-vehicle display can help drivers to attend relevant cues by highlighting them; a course of action that is safety-focused can also be suggested, and the driver can decide whether to follow this suggestion, or take a potentially less conservative action but still have the opportunity to act proactively rather than in a reactive manner.

Chapter 4

4 Driving Simulator Experiment 2: Anticipation in Automated Vehicles: The Effects of Experience and Distraction on Glance Behavior

4.1 Introduction

Experiment 2 aimed to investigate the influence of driving experience and secondary task engagement on anticipation in automated vehicles equipped with ACC and LKA. The experiment received approval from the University of Toronto Research Ethics Board (#35560). The same visual-manual task used in Experiment 1 was also adopted for Experiment 2. Each participant completed four drives in the simulator, each with an anticipatory scenario. As experiencing automation failures may affect drivers' trust in and reliance on the automated driving systems (Körber et al., 2018) and because failures are rare in a real driving environment (Blanco et al., 2016), the automation in this experiment was designed to be able to navigate all conflicts without intervention from the driver, to avoid impacting drivers' attitudes and/or behaviors in an unrealistic way. Thus, participants did not necessarily have to take control actions (i.e., change the automation settings or take control over the automation) even if they anticipated the potential traffic conflicts. In order to capture the drivers who anticipated potential conflicts but did not act, the analysis considered preparations for control actions also as anticipatory driving behaviors, as such preparations can also indicate drivers' awareness of potential traffic conflicts. In addition to anticipatory driving behaviors (i.e., pre-event control actions and preparations), glance behaviors as well as questionnaire responses about trust in and acceptance of automation were also analyzed. At the time of this writing, these findings are planned to be submitted to a journal. Secondary task engagement, physiological measures, self-reported workload, and perceived risk collected across the entire drive (rather than specifically around anticipatory scenarios) were analyzed and reported in another journal paper published in Transportation Research Record (He & Donmez, 2019), which is not included as a section in this dissertation, as they are not directly relevant to the analysis of anticipatory driving. However, the results of the paper are attached in Appendix W for readers' convenience.

Lastly, a comparison of Experiment 1 to Experiment 2 in relation to glance behaviors preceding and during anticipatory driving scenarios is reported near the end of this chapter. The anticipatory driving behaviors between these two experiments were not directly comparable, as different criteria were adopted across the two experiments for identifying anticipatory driving behaviors (i.e., control action only in Experiment 1; control action or preparation for control action in Experiment 2).

4.2 Method

4.2.1 Experiment design

The experiment had a 2×2 design, with driving experience (novice or experienced) and secondary task (yes or no) as independent variables, both implemented as between-subjects factors, again, in order to minimize learning and fatigue effects and to not repeat the same scenarios multiple times for a given participant. The criteria for the recruitment of novice and experienced drivers are described in Chapter 2.2. Participants were randomly assigned to a secondary task condition, perfectly balanced for gender. Each participant completed four experimental drives in the simulator with both ACC and LKA working simultaneously. Near the end of each drive, there was an anticipatory scenario where the participant could anticipate a potential traffic conflict based on the behavior of other traffic agents.

Table 7. Experimental design and participant age in Experiment 2

Group: Participant #	Secondary Task	Experience	Mean Age (Min - Max, SD)		
			Grand Total	**Male**	**Female**
1: #1-8	Yes	Novice	21.1 (18 - 27, 3.2)	20.8 (18 - 27, 3.6)	21.5 (19 - 26, 2.7)
2: #9-16		Experienced	37.4 (28 - 58, 9.4)	38.0 (28 - 50, 8.6)	36.8 (28 - 54, 10.2)
3: #17-24	No	Novice	21.6 (18 - 24, 1.9)	21.5 (19 - 23, 1.5)	21.8 (18 - 24, 2.3)
4: #25-32		Experienced	39.0 (28 - 52, 9.0)	36.0 (28 - 50, 8.8)	42.0 (33 - 52, 8.2)

4.2.2 Participants

A total of 32 participants completed the study, which is the same as the number of participants in Experiment 1, aiming to make these two studies comparable. Although participants' experience with driving automation was not screened, 26 out of the 32 total participants reported no experience with ACC and LKA systems. For those who reported to have experience with the automated driving systems, one participant reported using the systems several times a week (an experienced driver randomly assigned to the no-secondary-task condition), and five participants reported using either an ACC or an LKA system less than several times a year (one experienced driver in secondary-task condition; two experienced drivers in no-secondary-task condition; one novice driver in secondary-task condition; and one novice driver in no-secondary-task condition). In general, the novice drivers were younger than the experienced drivers (Table 7, $F(1,28) = 42.94$, $p < .0001$), which is to be expected and is representative of the driving population. No significant age difference was found between participants who were randomly assigned to the two secondary task conditions ($p = .7$). Table 7 also provides age range and standard deviation (SD) of age in each group. Further, in a post-experiment admission (see Table 2 and Appendix R) of a modified Complacency-Potential Factors Questionnaire (Singh et al., 1993), experienced drivers reported lower trust-related complacency toward commonly encountered automated devices (e.g., ATM) compared with novice drivers, mean difference (Δ)=1.00 on a scale of 1 (low) to 5 (high).

4.2.3 Driving task & secondary task

The driving tasks and the secondary task are the same as the ones used in Experiment 1. The readers can refer to Section 3.2.3 for the details of the driving task and Section 2.5 for the details of the visual-manual secondary task implemented in this experiment.

4.2.4 Procedure

Upon arrival, participant eligibility was verified, and written informed consent was obtained. The participants were then verbally introduced to the manual operation of the vehicle and then the vehicle automation (i.e., ACC and LKA). During this introduction, they also practiced engaging and disengaging the ACC and LKA, and changing the ACC cruise speed. Participants were also verbally informed about the limitations of both ACC (e.g., may not avoid a crash if intensive braking is required, does not respond to stationary objects) and LKA (e.g., may not work if lane markings are absent or not visible, such as at an intersection). They were then required to verbally repeat these limitations. If a participant did not repeat all limitations correctly, the experimenters would describe the limitations again until the participant repeated them correctly. The participants who were assigned to the secondary task condition were also trained on how to complete the secondary task and asked to practice performing the secondary task while not driving.

After the introduction session, participants completed a practice drive (minimum of 10 minutes) on a route similar to the ones in the experimental drives in terms of traffic density and road type. For the first 5 minutes of the drive, participants were required to drive without automation; then they were instructed to engage and disengage the ACC and LKA twice and then keep using the systems for a minimum of 5 minutes. If the participants indicated that they were not yet comfortable with the amount of practice they received, they were given additional practice time. In this practice drive, participants assigned to the secondary task condition were also asked to interact with the secondary task.

Following this initial practice drive, the participants were outfitted with the head-mounted eye-tracking system. Participants then completed one more practice drive that lasted for about 6 minutes, but they were told that this was an experimental drive. This drive was used to introduce an ACC failure to prime participants for the possibility of automation failures in order to calibrate their trust in and reliance on SAE Level-2 automation (Bahner, Hüper, & Manzey, 2008). All participants were told to prioritize driving safety and use both ACC and LKA when possible in this practice drive and all the following experimental drives. In the last practice drive and all experimental drives, participants were told to set the cruise speed of ACC at the speed limit, and keep driving on either the left or the right lane, unless it was necessary to change lanes (see Appendix T for detailed instructions). Participants were found to use ACC and LKA simultaneously for at least 80% of their total driving time.

Following these practice drives, participants completed the four experimental drives. Before each drive, the eye-tracker was re-calibrated. Participants were allowed a 5-minute rest after each drive, during which they completed a within-experiment questionnaire, as described in detail in Table 2 in Chapter 2.6. In the questionnaire, participants rated the automated driving system they used while considering ACC and LKA as a whole. They also finished a post-experiment questionnaire after all experimental drives, as also described in Table 2.

4.2.5 Data analyses and statistical models

Three categories of data were analyzed: 1) glance behaviors preceding (the 20 s interval preceding first cue onset) and during anticipatory scenarios; 2) anticipatory driving behaviors in anticipatory scenarios; 3) subjective responses on trust and acceptance toward the automated driving system used in the experiment.

This chapter focuses on drivers' glances to the anticipatory cues and secondary task display, as these types of glances were found to be associated with anticipatory driving in Experiment 1 in non-automated vehicles. Similar to the analyses for Experiment 1, each glance was defined from the gaze starting to move toward an area of interest (AOI) to its starting to move away from the AOI, following the definition in ISO 15007-1:2013(E) (International Organization for Standardization, 2014). Glances that fell partially within a data extraction period were also handled following the method in Seppelt et al. (2017). For example, if 0.7 seconds of a 1 second glance fell on the period of interest, then this glance was counted as 0.7 glances. Glances shorter than 100 ms were excluded from the analyses (Crundall & Underwood, 2011; Horrey & Wickens, 2007). In order to investigate whether drivers' behavior changed after cues became visible (i.e., after cue onset), an independent variable, "cue-onset", was also created. The cue-onset divided the data extraction period into two levels: the before-cue-onset period (from 20 seconds before cue onset to cue onset) and the after-cue-onset period (from cue onset to event onset or when the automation was disengaged, whichever occurred first). The length of before-cue-onset period was always 20 sec, and the average lengths of the after-cue-onset periods for Scenarios 1, 2, 3, and 4 were 14.1 s, 11.0 s, 12.6 s, and 8.1 s, respectively.

For glances toward the anticipatory cues, this chapter focuses on the time until first glance at cues (time between cues becoming visible and participants' first glance toward the cues) and the percent of time looking at the cues in after-cue-onset periods. If a participant never looked at an anticipatory cue, the time until first glance at cues was considered to be from the first cue becoming visible to event onset. For glances toward the secondary task display, the two metrics comprised the percent of time looking at the secondary task display and the rates of long glances (over 2 seconds) to the secondary task display within each data extraction period (i.e., before-cue-onset and after-cue-onset). Two seconds was used as the threshold for long glances based on crash risk research conducted in non-automated driving (Klauer et al., 2006), as there is no similar threshold for automated driving. Other metrics for glances toward the two AOIs, including the mean glance durations and rates of glances, were analyzed but not reported as they did not provide additional insights on driver monitoring. For the secondary task glance analyses, the variable “cue-onset” was included as an independent variable to describe the two data extraction periods so that it would be possible to assess whether glances toward the secondary task display differed before and after anticipatory cues were available.

Further, in order to understand the relationship between drivers’ glance behaviors and their actions in response to potential traffic conflicts, this chapter also analyzes anticipatory driving behaviors. The anticipatory behaviors included both pre-event actions (i.e., control actions prior to event onset; He & Donmez, 2018; Stahl et al., 2014) as well as pre-event preparations (i.e., driver preparations to adjust or disengage the automation). Pre-event actions included 1) pressing the brake pedal to decelerate and disengage the ACC, disengaging the ACC using the buttons on the steering wheel, or decreasing the set cruise speed of ACC in all scenarios; 2) accelerating by pressing the gas pedal or increasing the set cruise speed of ACC in Scenarios 2 and 3; and 3) turning the steering wheel to override the LKA and to change lanes in Scenario 4. The pre-event preparations included any identifiable foot or hand movements to prepare for a pre-event action, including moving foot to the gas or brake pedal, moving hands toward the steering wheel, and hovering fingers above any buttons that control the automation. Given that the scenarios in this experiment did not require driver takeover, it was important to expand earlier operationalizations of anticipatory driving behaviors in Experiment 1 and in Stahl et al. (2014).

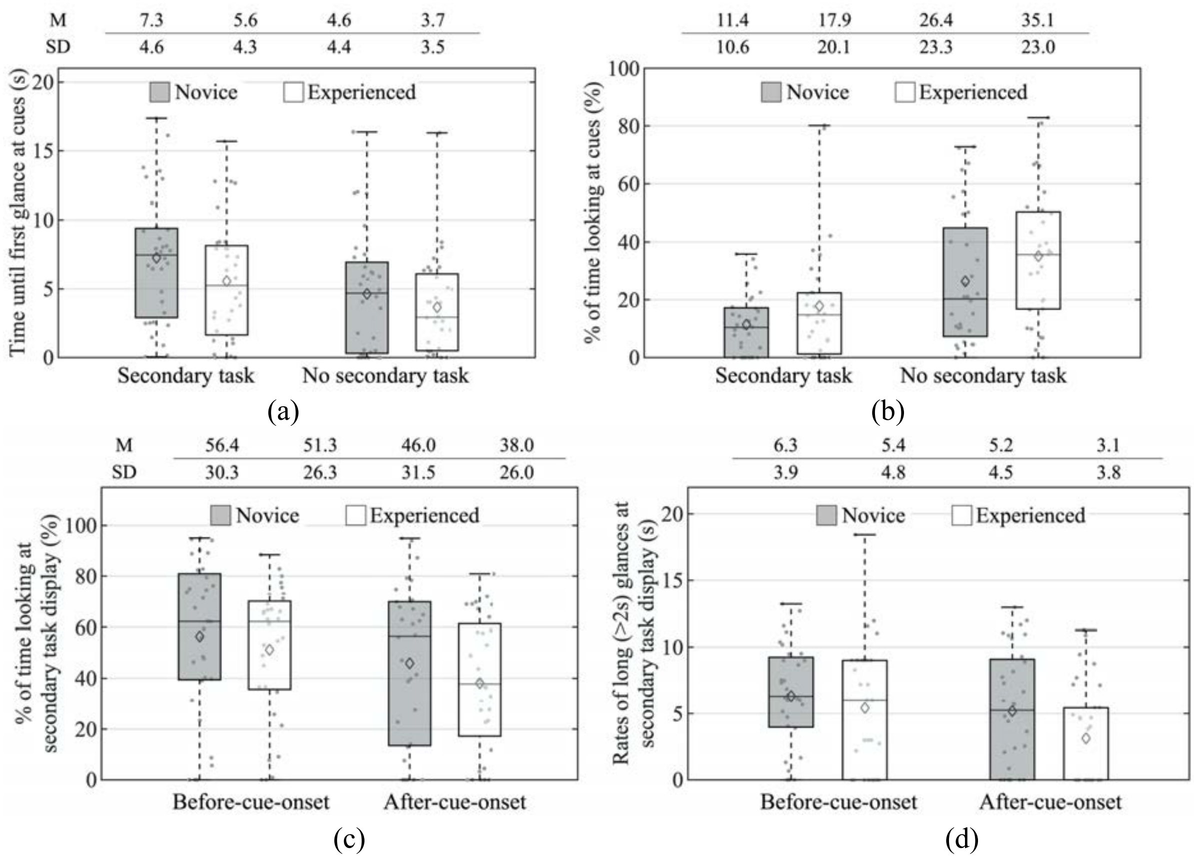
Three raters (one was the author of this dissertation, and other two raters were different from the ones in Experiment 1) blind to the driving experience level of participants labeled each scenario as having a pre-event action, a pre-event preparation, or no anticipatory behavior using eye-tracking videos and videos of participants’ feet and hands. One rater had 9 years of driving experience, one had 34 years of driving experience, and one had 1 year of driving experience. Again, raters were trained on the concept of anticipatory driving and the potential anticipatory driving behaviors in each scenario, but were not provided with strict criteria about what constituted a clear anticipatory driving behavior. Instead, they were instructed to make judgements by themselves based on the traffic situation and the concept of anticipatory driving. To reduce the risk of an unintentional foot or hand movement being labeled as an anticipatory behavior, at least one glance toward the anticipatory cues was required for a pre-event action or preparation. A Fleiss' Kappa (Fleiss, 1971) of 0.81, $z=15.87$, $p<.05$ (i.e., almost perfect) was reached before conflict resolution, and conflicts in judgment were resolved through discussions.

The binary variables (i.e., the exhibition of anticipatory behaviors) were analyzed using logistic regression models. The rate of long (>2s) glances was modeled using negative binomial regression, with the duration of the data extraction period used as the offset. Repeated measures (i.e., four scenarios by each participant) in the logistic and negative binomial models were accounted for using generalized estimating equations. All other variables were analyzed using repeated measures ANOVAs. Dependent variables were transformed when necessary to satisfy assumptions for repeated measures ANOVA. Significant main and interaction effects were followed by pairwise comparisons; any pairwise comparisons that are not reported in the results section were not significant (*p*>.05). Effects sizes are reported through 95% confidence intervals (CIs) for logistic and negative binomial regression models, and the partial omega squared (ω_p^2) (Keren & Lewis, 1979) for ANOVAs.

4.3 Results

4.3.1 Glance behaviors

As shown in Table 8 and Figure 13, the secondary task condition was associated with longer time until first glance at cues, ω_p^2=0.068, and a lower percentage of time spent looking at cues, ω_p^2=0.156, compared to the no secondary task condition. After cue onset, drivers spent a lower percentage of time spent looking at the secondary task display, ω_p^2=0.065, and exhibited 35% (95% CI: 21, 47) lower rate of long glances to the secondary task display. A marginally significant interaction effect was observed between experience and cue-onset for rates of long glances toward the secondary task display. Follow-up contrasts indicate that experienced drivers reduced rate of long glances to the secondary task display by 47% (95% CI: 27, 61) after cue onset, χ^2 (1)=15.61, $p<.0001$. There was no effect of experience on glances to the cues.

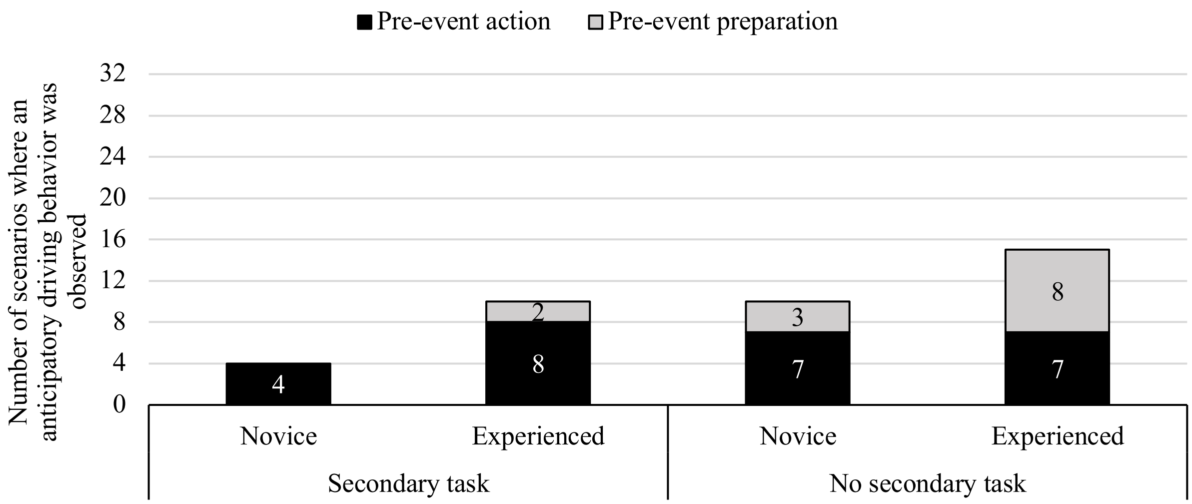


Note: The mean (M) and standard deviation (SD) values are provided at the top of each plot.

Figure 13. Boxplots of the metrics of glances on cues and the secondary task display in Experiment 2

4.3.2 Exhibition of anticipatory driving behaviors

The plots and statistical findings for anticipatory driving behaviors are presented in Table 8 and Figure 14. Compared to novice drivers, experienced drivers were more likely to exhibit anticipatory driving behaviors (pre-event action or pre-event preparation), with an odds ratio (OR) of 2.49, 95% CI: 1.04, 5.94, and the existence of the secondary task decreased the likelihood of anticipatory driving behaviors, OR=0.40, 95% CI: 0.17, 0.96. Given that prior anticipatory driving research for non-automated vehicles focused only on pre-event actions (Stahl et al., 2014, 2016, 2019), additional analysis was conducted to focus on the exhibition of just this type of anticipatory behavior for comparison purposes; no significant effects were found. When analyzing the scenarios where an anticipatory behavior was observed with regards to whether the behavior was a pre-event action or pre-event preparation, it was found that drivers in the secondary task condition were more likely to exhibit pre-event actions over pre-event preparation, OR=5.75, 95% CI: 1.47, 22.52.



Note: the maximum number of scenarios under each experimental condition is 32 (4 scenarios each participant and 8 participants within each condition). Each bar represents the number of scenarios where pre-event actions or pre-event preparations were observed under each experimental condition.

Figure 14. The number of scenarios where an anticipatory driving behavior was observed in Experiment 2

4.3.3 Relationship between glances and anticipatory driving behaviors

To further understand the relationship between glance behaviors and anticipatory driving behaviors, this chapter compares glance metrics between drives where anticipatory driving behaviors were observed and where no anticipatory driving behaviors were observed. For glance metrics toward anticipatory cues, data from drives where there was at least one glance toward an anticipatory cue was used (even for drives where no anticipatory driving behaviors were observed), as this was part of the criteria for identifying a response as an anticipatory driving behavior. As shown in Figure 15b, it was found that in drives where an anticipatory driving behavior was observed, drivers spent a lower percent of time looking at the secondary task display, $F(1,109)=8.34$, $p=.005$, $\omega_p^2=0.054$.

System acceptance and trust ratings were also compared between drives with and without anticipatory driving behaviors. Drivers rated the automated driving system as less useful in drives where anticipatory behaviors were observed, $F(1,95)=7.48$, $p=.008$, $\Delta=0.13$, 95%CI: 0.04, 0.23,0.0482. This was the only significant finding for system acceptance and trust ratings in this study.

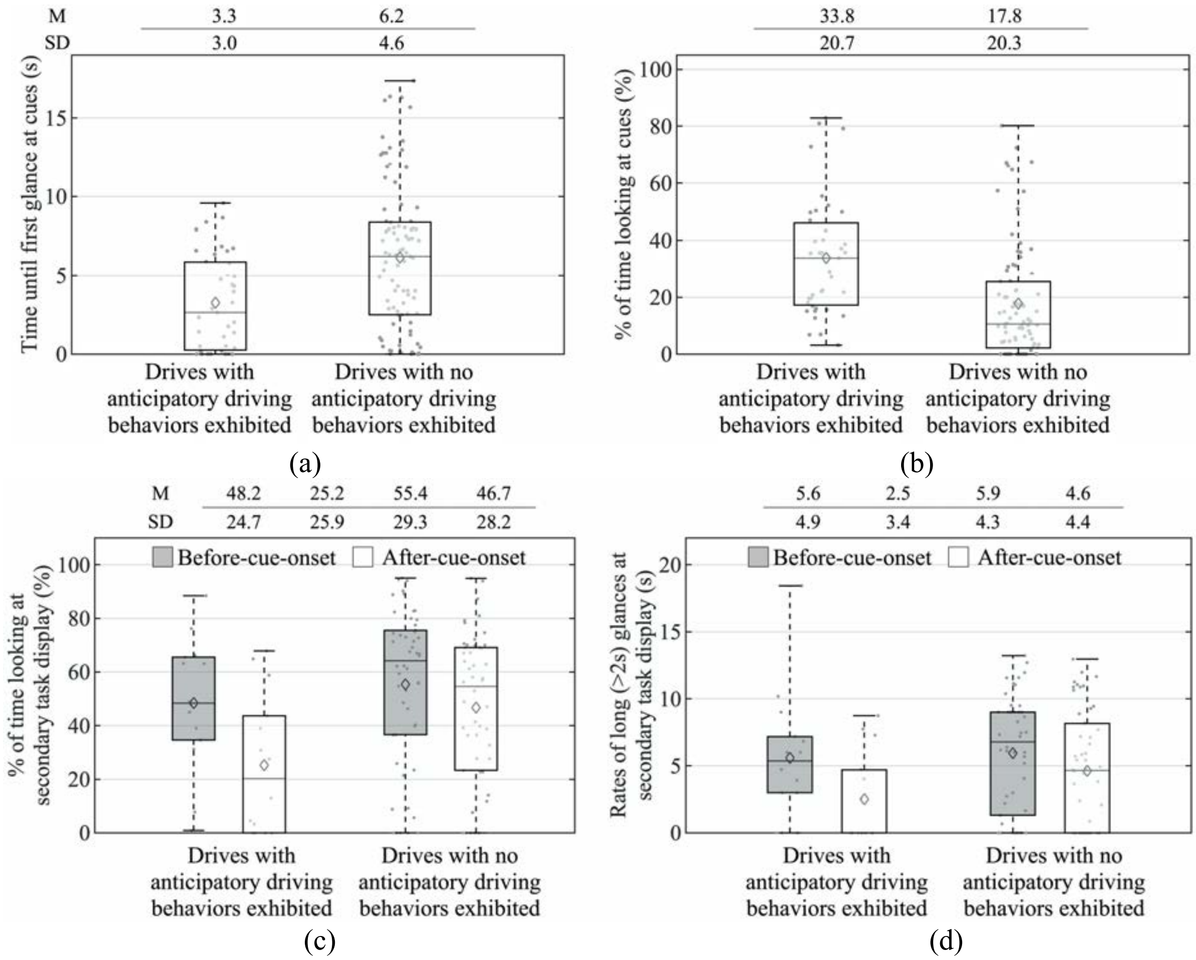


Figure 15. Boxplots of glances on cues and secondary task display across drives where anticipatory driving behaviors were and were not observed in Experiment 2

Table 8. Statistical results for glance measures and anticipatory driving behaviors in Experiment 2

	Dependent variables		Independent variables: Experience	Secondary task	Experience* Secondary task	Cue-onset	Experience* Cue-onset
Glances toward cues	Time until first glance	*F*-value	F(1,28)=1.57	F(1,28)=7.25	F(1,28)=0.46	-	-
		p	p=.22	p=.01**	p=.50	-	-
	% of time spent looking	*F*-value	F(1,28)=2.38	F(1,28)=13.96	F(1,28)=0.06	-	-
		p	p=.13	p=.0008**	p=.81	-	-
Glances toward secondary task display	% of time spent looking	*F*-value	F(1,14)=0.52	-	-	F(1,110)=7.62	F(1,110)=0.10
		p	p=.48	-	-	p=.007**	p=.75
	Rate of long (>2s) glances	χ^2-value	χ^2(1)=1.59	-	-	χ^2(1)=17.68	χ^2(1)=3.67
		p	p=.21	-	-	p=<.0001**	p=.055*
Anticipatory driving behaviors	Anticipatory driving behavior *(yes vs. no)*	χ^2-value	χ^2(1)=4.20	χ^2(1)=4.20	χ^2(1)=0.31	-	-
		p	p=.04**	p=.04**	p=.58	-	-
	Pre-event action *(yes vs. no)*	χ^2-value	χ^2(1)=0.24	χ^2(1)=0.69	χ^2(1)=0.69	-	-
		p	p=.63	p=.41	p=.41	-	-
	Type of anticipatory behavior *(pre-event action vs. pre-event preparation)*	χ^2-value	χ^2(1)=2.48	χ^2(1)=6.31	-	-	-
		p	p=.12	p=.01**	-	-	-

Note: In this table, ** marks significant results (p<.05) and * marks marginally significant results (.05<p<.1). The interaction of experience and secondary task for the type of anticipatory driving behaviors is not estimable because there were no instances of pre-event preparation for novice drivers in the secondary task condition. The first column lists the type of independent variables and the second column lists the independent variables investigated in the analysis and their interactions; the other columns present the statistical results for different dependent variables. A dash ("-") indicates that the corresponding independent variable was not applicable for that measure and was not included in its statistical analysis (e.g., cue-onset is not a relevant variable for analyzing % time looking at cues as this measure has a value of zero before cue-onset).

4.4 Discussion

Similar to what has been observed for non-automated vehicles in Experiment 1, in automated vehicles, the presence of a secondary task impaired driver attention to anticipatory cues indicating potential traffic conflicts and impeded anticipatory driving behaviors. However, as opposed to what has been observed in Experiment 1 and in other anticipatory driving studies in non-automated vehicles (Stahl et al., 2019), driving experience did not enhance driver attention to anticipatory cues in automated vehicles. Novice drivers are ordinarily less skilled in handling non-automated vehicles compared to experienced drivers (Bjørnskau & Sagberg, 2005), and thus they require more effort to execute the manual control of the vehicle and may have less remaining attentional capacity to identify and attend to anticipatory cues. In automated vehicles, on the other hand, as automation frees up drivers from manually controlling the vehicle, both novice and experienced drivers may have similar spare attentional capacity to monitor the road, which may explain why no difference between experienced and novice drivers in their glances toward anticipatory cues was found.

Although experienced drivers did not spend a higher percent of time looking at the cues, nor made their first glance to the cues sooner than novice drivers, they were more likely to exhibit anticipatory driving behaviors. These findings indicate that visual attention to anticipatory cues may not be the only factor that influences anticipatory driving behaviors in automated vehicles. One possibility is that while experienced and novice drivers allocated a similar amount of visual attention toward anticipatory cues, experienced drivers were better able at interpreting the information from the cues to anticipate potential traffic conflicts, similar to what has been suggested in hazard perception studies (Jackson et al., 2009). This seems to be supported by a marginal interaction effect between experience and cue-onset for rates of long glances toward the secondary task: experienced drivers reduced their rate of long glances to the secondary task display after cue onset while novice drivers did not. This finding suggests that although experienced drivers did not allocate more visual attention to anticipatory cues, they may still be better than novice drivers at adapting their secondary task engagement based on traffic complexity in automated vehicles. It should be noted that the results of visual attention to the secondary task reported in this chapter are different from those reported in our previous paper

(He & Donmez, 2019), where it was found that experienced drivers exhibited lower rates of long glances to secondary task display. In the current chapter, the metrics for visual attention to the secondary task were extracted for the anticipatory scenarios, which occurred at the end of each experimental drive and lasted a relatively short time period (e.g., 28.1 seconds in average in Scenario 4); whereas in He and Donmez (2019), visual attention to the secondary task over the entire experimental drives was analyzed, which was 6.05 minutes (SD: 0.81) on average.

Drivers' attitudes toward automation may also influence anticipation in automated vehicles. The automated driving system was perceived as less useful in drives where anticipatory driving behaviors were observed. In these drives, drivers spent a lower percent of time looking at the secondary task display, which has previously been used as an indicator of reliance on driving automation (Körber et al., 2018). These results suggest that perceived usefulness of the automation and how much drivers relied on the automation may have affected their anticipatory driving behaviors. However, in drives with anticipatory driving behaviors, drivers did not report higher trust in the automated driving systems they were using, suggesting that trust and reliance may not necessarily be correlated in automated vehicles and there are other factors that may influence reliance. The results from this study also showed that although no difference was observed between novice and experience drivers in terms of their trust in the automated driving systems, experienced drivers reported lower trust-related complacency toward commonly encountered automated devices. The drivers in this study had limited experience with the automated driving systems both in the experiment and in their daily life, thus their initial trust in and reliance on the automated driving systems might be based on their attitudes toward automation in daily life (Lee & Kolodge, 2020). This may have explained experienced drivers' higher likelihood of exhibiting anticipatory driving behaviors in the experiment, i.e., the experienced drivers tended to rely less on automation compared with the novice. However, further research with larger sample sizes is needed to validate these findings and explore the potential factors that may have affected drivers' reliance on the automated driving systems, which would provide additional insights on the factors that influence anticipatory driving in automated vehicles.

In summary, the findings from this study provide insights on the role of driving experience and secondary task engagement in automated vehicles. Experienced drivers, who have been found to be better at perceiving traffic situations, are more likely to exhibit anticipatory driving behaviors (Stahl et al., 2014, 2016, 2019), while a secondary task impedes anticipatory driving in automated vehicles. The effect of experience on anticipatory driving behaviors suggests that driving experience may not only influence drivers' behaviors in automated vehicles at an operational level (e.g., smoother control of speed among novice drivers with automation but not among experienced drivers; Young & Stanton, 2007) but also at a tactical level (i.e., the anticipation of potential traffic conflicts). Thus, training that aims to improve novice drivers' ability to identify and perceive traffic situations may facilitate their preparation for potential traffic conflicts that require their intervention. Further, secondary tasks that can lead to distractions may still need to be restricted in automated vehicles. The findings also suggest the importance of calibrating drivers' reliance toward the automation, as increased reliance (in the form of shifting visual attention away from the road and onto the secondary task) is associated with a lower likelihood of preparing proactively for potential traffic conflicts (i.e., anticipatory driving). However, it is important to reiterate that in all of the scenarios in this experiment, the automation could handle the situation without intervention from the drivers. Thus, it is possible that some drivers could have anticipated the potential traffic conflict but chose not to disengage the automation or prepare to take an action. These drivers may be those who have higher trust in and higher reliance on the automation. Unfortunately, the methodology in this study could not distinguish drivers who anticipated but did not act proactively from drivers who did not anticipate the potential traffic conflict. Future research may address this limitation by incorporating other measures (e.g., post-experiment questionnaires regarding participants' understanding of the scenarios) to assess whether participants anticipated the traffic conflict or not. Lastly, drivers' behaviors might differ in situations where a pre-event action is necessary to avoid a collision (Eriksson & Stanton, 2017b), and thus future studies may need to investigate drivers' anticipatory driving behaviors in critical situations.

4.5 Comparison of Experiment 1 and Experiment 2 in terms of glance behaviors preceding and during anticipatory scenarios

4.5.1 Dependent variables and statistical models

In this section, drivers' visual attention allocation related to anticipation is compared across non-automated and automated vehicles (i.e., Experiment 1 vs. Experiment 2). Specifically, this section focuses on drivers' glances toward cues and the secondary task display prior to and during anticipatory driving scenarios. The metrics for glances to cues included the time until first glance on cues, percent of time looking at cues, mean glance duration on cues, and rates of glances toward cues. The metrics for the glances to the secondary task included percent of time looking at, rate of long (>2s) glances toward, mean glance duration on, and rate of glances toward the secondary task display. As was done for Experiment 1 and Experiment 2 individually, the analyses in this section focus on two data extraction periods: before-cue-onset and after-cue-onset. Following the definitions of the periods in Experiment 1 and Experiment 2, the before-cue-onset period was from 20 seconds before the cue onset to the cue onset, and the after-cue-onset period was from cue onset to event onset (in Experiment 1) or from cue onset to event onset or automation disengagement, whichever happened first (in Experiment 2).

All models were built in SAS University Edition V9.4. The rates of glances were modeled using a negative binomial regression with repeated measures accounted for through Generalized Estimating Equations. All other variables were modeled using mixed models with participants introduced as a random factor and the variance-covariance structure chosen based on the Bayesian Information Criterion. Significant main and interaction effects were followed by pairwise comparisons. Any pairwise comparisons that were not reported were not significant ($p>.05$). Dependent variables were transformed when necessary to satisfy mixed model assumptions.

Table 9. Models comparing glances to anticipatory cues between Experiment 1 and Experiment 2

Measure	Automation	Experience	Secondary Task	Automation* Experience	Automation* Secondary Task	Experience * Secondary Task
Time until first glance (s)	$F(1,246)=0.04$ $p=.9$	$F(1,246)=9.04$ $p=.003$*	$F(1,246)=13.44$ $p=.0003$*	$F(1,246)=1.13$ $p=.3$	$F(1,246)=0.26$ $p=.6$	$F(1,246)=1.18$ $p=.3$
Percent time looking (%)	$F(1,57.1)=6.27$ $p=.02$*	$F(1,57.1)=7.07$ $p=.01$*	$F(1,57.1)=25.98$ $p<.0001$*	$F(1,57.1)=0.38$ $p=.5$	$F(1,57.1)=10.83$ $p=.002$*	$F(1,57.1)=0.12$ $p=.7$
Duration of glances (ms)	$F(1,56.9)=5.75$ $p=.02$*	$F(1,56.9)=0.08$ $p=.8$	$F(1,56.9)=11.63$ $p=.001$*	$F(1,56.9)=1.66$ $p=.2$	$F(1,56.9)=12.37$ $p=.0009$*	$F(1,56.9)=0.06$ $p=.8$
Rate of glances (/min)	$\chi^2(1)=0.89$ $p=.3$	$\chi^2(1)=15.65$ $p<.0001$*	$\chi^2(1)=20.81$ $p<.0001$*	$\chi^2(1)=.20$ $p=.7$	$\chi^2(1)=2.26$ $p=.13$	$\chi^2(1)=2.41$ $p=.12$

Note: * p<.05. In Table 9 and Table 10, the first column lists the independent variables investigated in the analysis and their interactions; the other columns present the statistical results for different dependent variables.

Table 10. Models comparing glances to secondary task display between Experiment 1 and Experiment 2

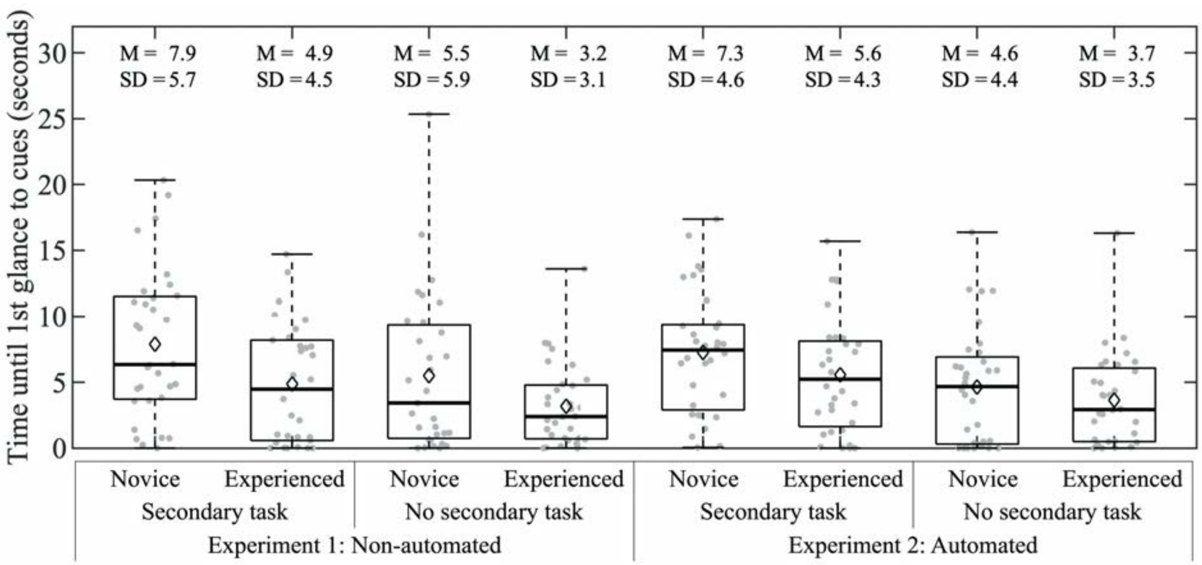
Measure	Automation	Experience	Cue-onset	Automation* Experience	Automation* Cue-onset	Experience * Cue-onset
Percent time looking (%)	$F(1,28)=7.67$ $p=.01$*	$F(1,28)=0.16$ $p=.7$	$F(1,217)=12.41$ $p=.0005$*	$F(1,28)=0.58$ $p =.5$	$F(1,217)=1.08$ $p =.3$	$F(1,217)=0.00$ $p =.99$
Rate of long (>2s) glances (/min)	$\chi^2(1)=19.82$ $p<.0001$*	$\chi^2(1)=14.16$ $p=.0002$*	$\chi^2(1)=7.95$ $p=.005$*	$\chi^2(1)=7.78$ $p=.005$*	$\chi^2(1)=0.23$ $p=.3$	$\chi^2(1)=2.64$ $p=.10$
Duration of glances (ms)	$F(1,28.3)=10.40$ $p=.003$*	$F(1,28.3)=7.69$ $p=.01$*	$F(1,217)=3.27$ $p=.07$	$F(1,28.3)=1.67$ $p=.2$	$F(1,217)=0.96$ $p=.3$	$F(1,217)=0.45$ $p=.5$
Rate of glances (/min)	$\chi^2(1)=4.59$ $p=.03$*	$\chi^2(1)=10.43$ $p=.001$*	$\chi^2(1)=6.32$ $p=.01$*	$\chi^2(1)=0.08$ $p=.8$	$\chi^2(1)=0.23$ $p=.3$	$\chi^2(1)=0.00$ $p=.96$

Note: * p<.05.

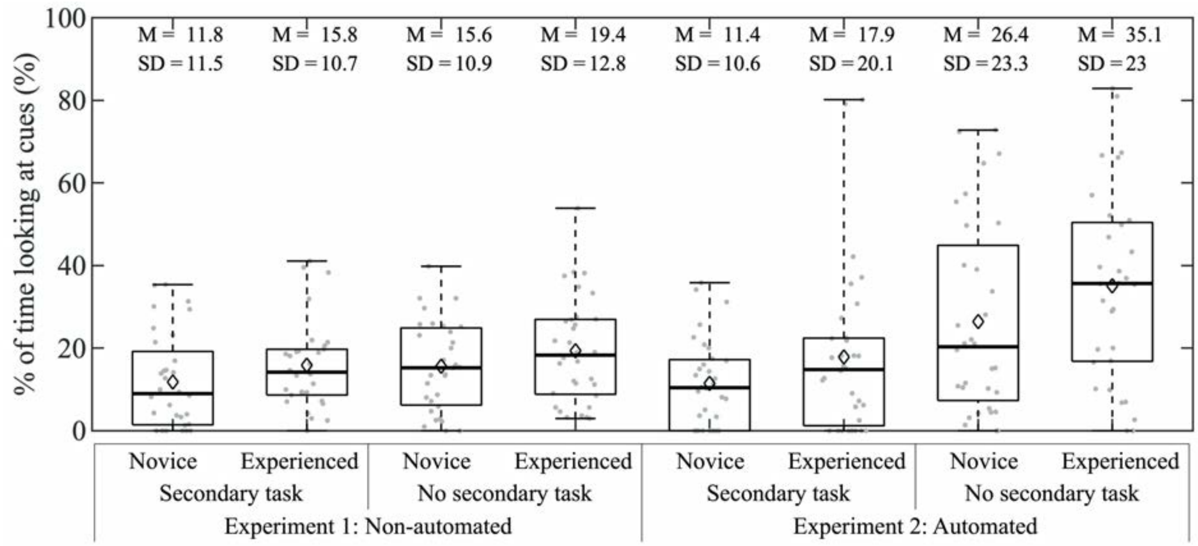
4.5.2 Results

4.5.2.1 Glances to anticipatory cues

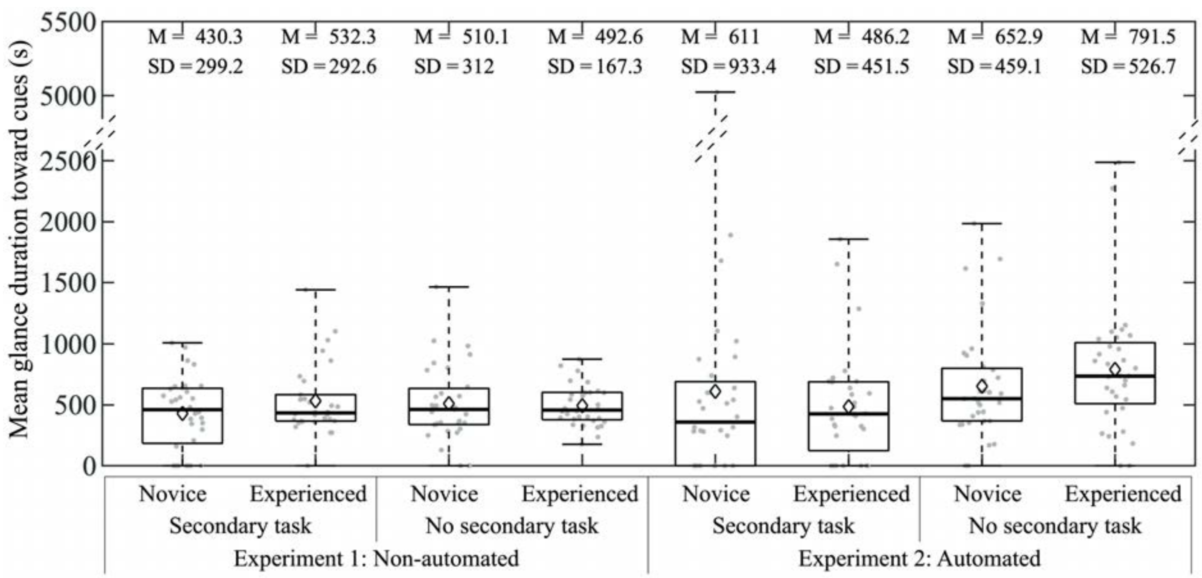
As shown in Table 9 and Figure 16, interaction effects were observed between the secondary task availability and the automation in terms of percent of time spent looking at the cues (Figure 16b), $F(1,57.1)=10.83$, $p=.0017$, and mean glance duration on cues (Figure 16c), $F(1,56.9)=12.37$, $p=.0009$. When there was no secondary task, drivers in the automated vehicle with ACC and LKA (Experiment 2) spent a higher percent of time looking at cues, $t(56.9)=4.10$, $p=.0001$, and had a longer mean glance duration on cues, $t(56.8)=4.18$, $p=.0001$, compared to drivers in the non-automated vehicle (Experiment 1). Further, in the automated vehicle (Experiment 2), drivers in the secondary task conditions spent a lower percent of time looking at the cues, $t(56.4)=5.95$, $p<.0001$, and exhibited lower mean glance duration toward the cues, $t(56.7)=-4.90$, $p<.0001$, compared with drivers in the no secondary task conditions. These effects were not observed in the non-automated vehicle (Experiment 1).



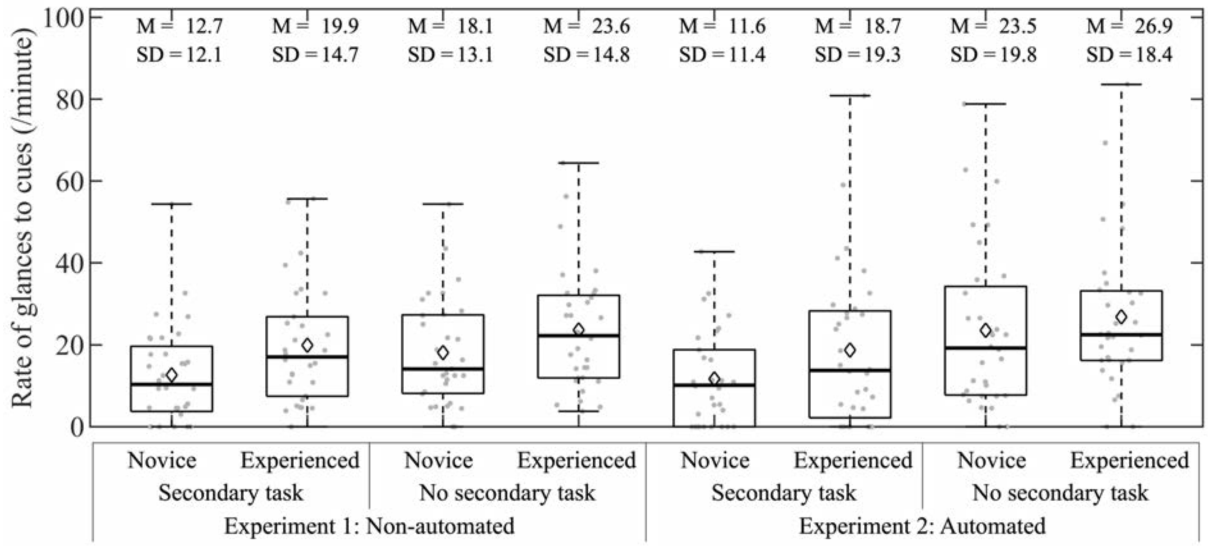
(a)


M = 11.8
SD = 11.5
M = 15.8
SD = 10.7
M = 15.6
SD = 10.9
M = 19.4
SD = 12.8
M = 11.4
SD = 10.6
M = 17.9
SD = 20.1
M = 26.4
SD = 23.3
M = 35.1
SD = 23
% of time looking at cues (%)
0
20
40
60
80
100
Novice
Experienced
Secondary task
No secondary task
Experiment 1: Non-automated
Experiment 2: Automated

(b)


M = 430.3
SD = 299.2
M = 532.3
SD = 292.6
M = 510.1
SD = 312
M = 492.6
SD = 167.3
M = 611
SD = 933.4
M = 486.2
SD = 451.5
M = 652.9
SD = 459.1
M = 791.5
SD = 526.7
Mean glance duration toward cues (s)
0
500
1000
1500
2000
2500
5000
5500
Novice
Experienced
Secondary task
No secondary task
Experiment 1: Non-automated
Experiment 2: Automated

(c)



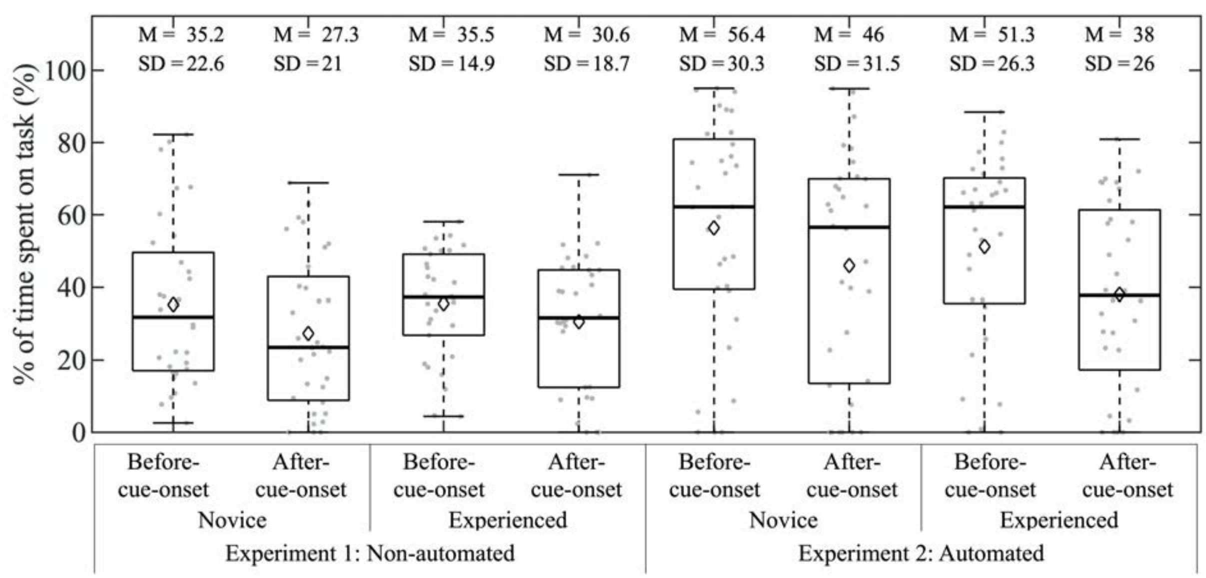
(d)

Figure 16. Glances toward the anticipatory cues in Experiment 1 and Experiment 2: a) time until first glance; b) percent of time spent looking; c) mean glance duration; d) rate of glances

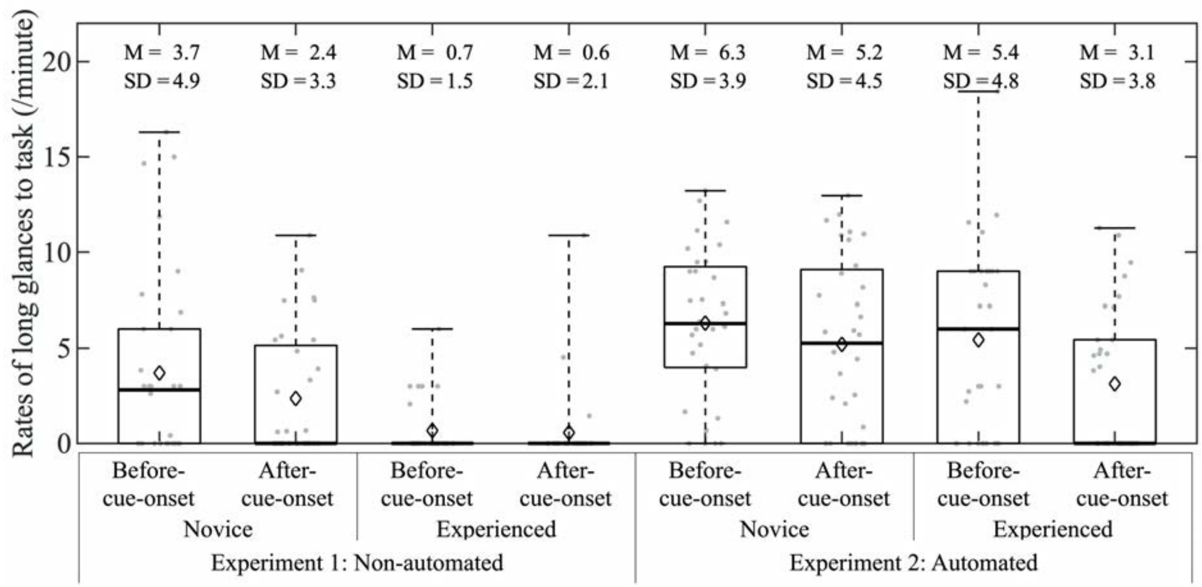
4.5.2.2 Glances to secondary task display

As shown in Table 10 and Figure 17, compared to those in the non-automated vehicle (Experiment 1), drivers in the automated vehicle (Experiment 2) spent a higher percent of time looking at the secondary task display (Figure 17a), $F(1,28)=7.67$, $p=.01$, had a longer mean glance duration toward the secondary task display (Figure 17c), $F(1,28.3)=10.40$, $p=.003$, and had lower rates of glances toward the secondary task display (Figure 17d), $\chi^2(1)=4.59$, $p=.03$.

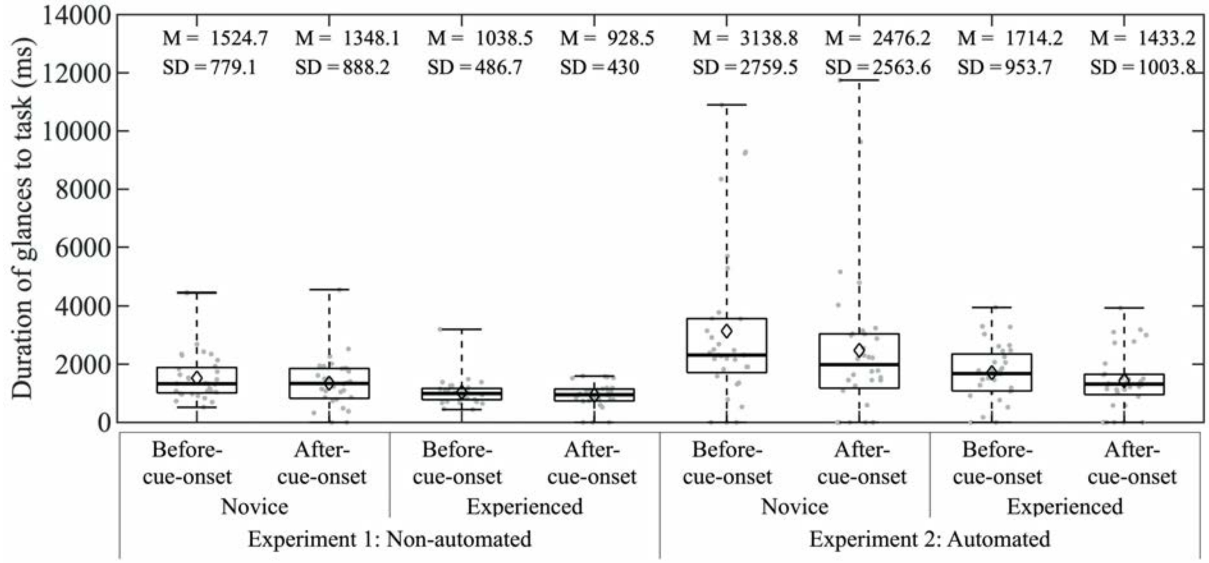
An interaction between experience and automation was observed for the rate of long (>2s) glances toward the secondary task display (Figure 17b), $\chi^2(1)=7.78$, $p=.005$. Experienced drivers had higher rates of long glances toward the secondary task display in the automated vehicle (Experiment 2) compared to experienced drivers in the non-automated vehicle (Experiment 1), $\chi^2(1)=18.39$, $p<.0001$. In the non-automated vehicle (Experiment 1), experienced drivers had lower rates of long glances toward the secondary task display, $\chi^2(1)=13.85$, $p=.0002$.


M = 35.2
SD = 22.6
M = 27.3
SD = 21
M = 35.5
SD = 14.9
M = 30.6
SD = 18.7
M = 56.4
SD = 30.3
M = 46
SD = 31.5
M = 51.3
SD = 26.3
M = 38
SD = 26
% of time spent on task (%)
100
80
60
40
20
0
Before-cue-onset
After-cue-onset
Novice
Before-cue-onset
After-cue-onset
Experienced
Experiment 1: Non-automated
Before-cue-onset
After-cue-onset
Novice
Before-cue-onset
After-cue-onset
Experienced
Experiment 2: Automated

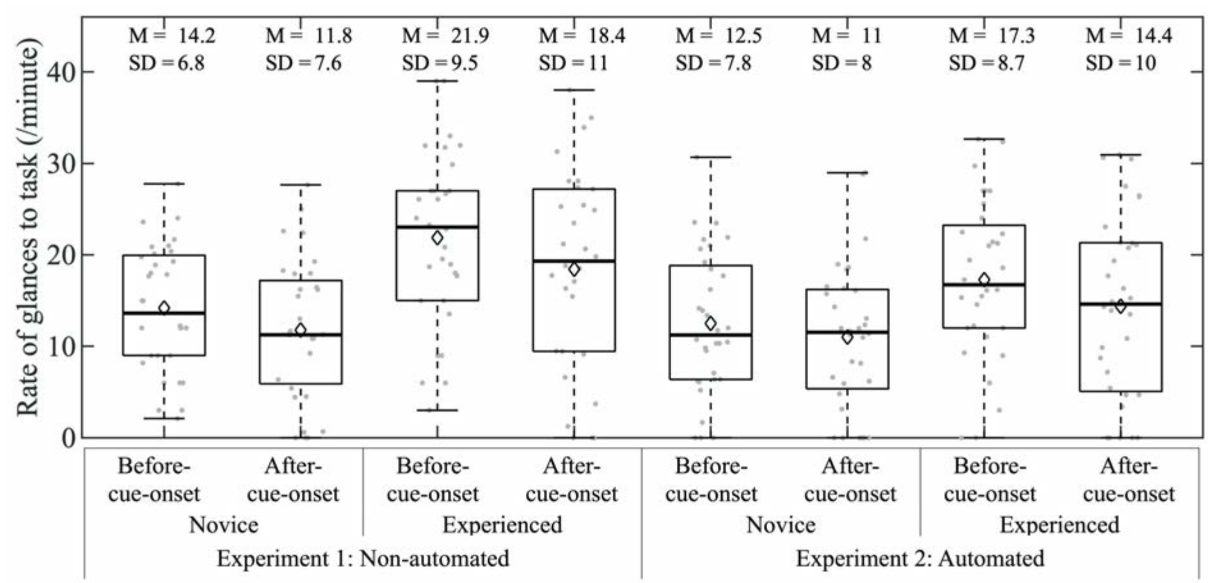
(a)


M = 3.7
SD = 4.9
M = 2.4
SD = 3.3
M = 0.7
SD = 1.5
M = 0.6
SD = 2.1
M = 6.3
SD = 3.9
M = 5.2
SD = 4.5
M = 5.4
SD = 4.8
M = 3.1
SD = 3.8
Rates of long glances to task (/minute)
20
15
10
5
0
Before-cue-onset
After-cue-onset
Novice
Before-cue-onset
After-cue-onset
Experienced
Experiment 1: Non-automated
Before-cue-onset
After-cue-onset
Novice
Before-cue-onset
After-cue-onset
Experienced
Experiment 2: Automated

(b)



(c)



(d)

Figure 17. Glances toward the secondary task preceding and in anticipatory scenarios in Experiment 1 and Experiment 2: a) percent of time spent looking; b) rate of long glances; c) mean glance duration; d) rate of glances

4.5.3 Discussion

When there was no secondary task, drivers in a simulated automated vehicle with ACC and LKA spent a higher percent of time looking at and had a longer mean glance duration toward anticipatory cues. As drivers no longer needed to control the vehicle continuously when using ACC and LKA, they could have had more spare attentional capacity to observe the traffic situation, which likely made it possible for them to notice and allocate more attention to areas of importance (i.e., anticipatory cues) that are relevant to the anticipation of traffic. However, when provided with a non-driving task in an automated vehicle, agreeing with the findings in de Winter et al. (2014) and Jamson et al. (2013), drivers seemed more likely to allocate their spare attention to the non-driving task. In other words, drivers in the automated vehicle spent a higher percent of time looking at and had longer glances toward the secondary task display compared to drivers in the non-automated vehicle. This shift of attention to the secondary task may explain why drivers in the automated vehicle did not glance more to the anticipatory cues compared to drivers in the non-automated vehicle in the presence of a secondary task. Previous research can provide some insights on this interaction effect of automation and distraction on drivers' behaviors. For example, Merat et al. (2012) found that when drivers were not distracted, in automated (with ACC and LKA) and non-automated vehicle settings, a similar proportion of drivers changed lanes in response to a critical event (obstacle in the ego-lane, pre-warned by a sign about 1500 m before the obstacle). On the other hand, when drivers were distracted, few lane changes were made overall, especially in non-automated vehicles. Our results extend this finding by revealing that an interaction effect between distraction and automation existed also for glance behaviors, particularly glances to anticipatory cues that can indicate upcoming traffic conflicts. This indicates that driver distraction needs to be considered when investigating behaviors in automated vehicles, as drivers might exhibit different behaviors depending on whether they are distracted.

Driving experience also had an influence on secondary task engagement behaviors in automated vehicles. That is, although experienced drivers exhibited a lower rate of long (>2 sec) glances to the secondary task compared to novice drivers in the non-automated vehicle, experienced drivers also had higher rates of long glances on secondary task display in the automated vehicle compared to experienced drivers in the non-automated vehicle. These results do not fully agree with what was reported in He and Donmez (2019) (see Appendix W). For those analyses, it was found that experienced drivers exhibited safer non-driving related glances in both automated and non-automated vehicles; i.e., experienced drivers had lower rates of glances, lower rates of long glances, and shorter mean glance duration compared with novice drivers. In He and Donmez (2019), it was also found that experienced drivers were less affected by the automation compared to novices. That is, novice drivers had longer mean glance duration on the secondary task in automated vehicles compared to that in non-automated vehicles, whereas experienced drivers did not. The difference between the findings reported in this section and in He and Donmez (2019) might be because of the large difference in data extraction periods between the two analysis. That is, less than 30 seconds of data were extracted from each drive and reported in this section, while the entirety of the 5-minute long drives was reported in He and Donmez (2019). The longer data extraction period in He and Donmez (2019) also includes large portions of the drive without critical events, while the analysis in this section focuses on the short periods when drivers were experiencing complex traffic situations that could potentially lead to conflicts.

Focusing the analysis on the period in which drivers are experiencing the anticipatory scenarios brought to light the difficulties novice drivers potentially face in adapting their visual attention allocation to complex traffic events, which has also been demonstrated by Crundall and Underwood (1998). The deterioration of novice drivers' visual attention allocation upon introducing automation, observed in He and Donmez (2019), was not observed in the current analysis given that the current analysis found novice drivers to poorly allocate their attention when they experienced anticipatory scenarios in non-automated driving (e.g., novice drivers already exhibited higher rates of long glances to the secondary task compared to experienced drivers in non-automated vehicles). Further research should explore how both novice and experienced drivers adapt their visual attention allocation to complex traffic scenarios in automated driving, with larger sample sizes and a wider variety of scenarios.

Chapter 5

5 Driving Simulator Experiment 3: In-vehicle Displays to Support Driver Anticipation of Traffic Conflicts in Automated and Connected Vehicles

5.1 Introduction

The aim of Experiment 3 was to investigate the effectiveness of display designs in supporting anticipatory driving in automated vehicles. This third experiment was approved by the Research Ethics Board in the University of Toronto with the protocol number #36674. At the time of this writing, this work is under consideration by *Accident Analysis and Prevention* requiring minor revision and modifications.

Given that in automated vehicles "*a key component of driver engagement is cognitive (understanding the need for action), rather than purely visual (looking at the threat), or having hands on wheel*" (Victor et al., 2018, p. 1095), an in-vehicle display that aims to support anticipatory driving in an automated vehicle should help drivers understand driving situations promptly. In addition, previous studies have pointed out that drivers' takeover behavior depends on their expectation of the system limits (Kircher, Larsson, & Hultgren, 2014). Studies have also emphasized the importance of informing automation capability in handover scenarios (Eriksson & Stanton, 2015, 2017a), which may especially be the case for supporting anticipatory driving in automated vehicles, as drivers will need to predict the development of the traffic situation based on how the automation may respond to the evolving traffic situation. Thus, the display should also provide automation capability (AC) information to drivers. Lastly, the display content needs to be organized in an efficient and minimally distracting way, for example, using augmented reality (AR) technology (e.g., showing the information on the windshield), which has been found to be effective in reducing response time to automation failures (Damböck et al., 2012; Debernard et al., 2016).

In this experiment, the effectiveness of two different in-vehicle displays for supporting anticipatory driving in automated vehicles were investigated. One of the displays (TORAC) provided a TOR (Takeover Request) to indicate an event that potentially required the driver's intervention and provided dynamic information about the automation capability (AC). The idea of combining TORs with AC information has been used widely in previous automated driving research to facilitate transfers of control from the automation to the driver. The other display (STTORAC) provided a TOR and automation capability (AC) information, but additionally provided information about the surrounding traffic (ST) situation to assist the driver in gaining an awareness of the environment. Both displays were compared against a baseline display that showed only static information about whether the automation was engaged.

Further, Eriksson and Stanton (2017b) found that drivers took a longer time to resume control after a TOR when they were allowed to do so at their own pace compared to when their immediate action was required. Given that drivers may exhibit different behaviors in situations with different criticality, the anticipatory driving scenarios used in Experiment 1 and Experiment 2 were modified for this experiment (as explained in the following section). Two criticality levels were investigated in this experiment: one set of scenarios did not necessitate an action from the driver to avoid a collision, whereas the other set did. Given that drivers are more likely to engage in non-driving tasks in automated vehicles (de Winter et al., 2014) and that anticipatory driving behaviors can be impeded by distraction according to the results from the previous two experiments, drivers were allowed to engage in a visual-manual secondary task throughout the experiment. Again, the secondary task was self-paced (exactly the same as the one used in Experiments 1 and 2, see Chapter 2.5) so that the drivers could modulate their distraction engagement based on their anticipation of how the surrounding traffic could evolve. Driving experience was also considered as a factor in this experiment, as experienced drivers were found to be more efficient at modulating their non-driving task engagement in non-automated vehicles in Experiment 1, and they exhibited more anticipatory driving behaviors in both Experiments 1 and 2.

5.2 Method

5.2.1 Experiment design

The experiment was a 2 × 3 × 2 mixed design with driving experience (novice vs. experienced) and display type (baseline, TORAC, STTORAC) as between-subjects factors, and the scenario criticality (action-necessary vs. action-not-necessary) as the within-subject factor. Each participant experienced four action-necessary (A-N) scenarios and four action-not-necessary (A-not-N) scenarios. In A-N scenarios, the driver had to intervene to avoid a collision (by either taking over control of the vehicle or adjusting the settings of the automation, e.g., by changing ACC speed) as the required response exceeded the automation capabilities. In the A-not-N scenarios, it was not necessary for the driver to intervene in the driving task to avoid a collision as the automation was able to perform the response (however, drivers were still allowed to step in if they felt necessary to do so.) The order of scenario criticality was counterbalanced as described in Chapter 5.2.3 Driving Task. All participants were provided a visual-manual secondary task (as described in Chapter 2.5) during the drives.

Table 11. Between subject factors (i.e., display type and driving experience) and participant age in Experiment 3

Display Type	Driving Experience	Mean Age (Min - Max, SD)		
		Grand Total	Male	Female
Baseline display	Novice (n = 8)	20.0 (18 - 26, 2.3)	20.8 (18 - 26, 3.1)	19.3 (19 - 20, 0.4)
	Experienced (n = 8)	33.5 (25 - 47, 6.9)	26.5 (25 - 47, 7.8)	30.5 (27 - 37, 4.1)
TORAC display	Novice (n = 8)	21.3 (18 - 26, 2.7)	22.5 (18 - 26, 3.2)	20.0 (19 - 22, 1.2)
	Experienced (n = 8)	34.0 (27 - 48, 6.6)	35.5 (27 - 48, 8.3)	32.5 (29 - 38, 3.5)
STTORAC display	Novice (n = 8)	20.4 (18 - 25, 2.5)	20.0 (18 - 25, 2.9)	20.8 (18 - 23, 1.9)
	Experienced (n = 8)	33.3 (29 - 41, 3.7)	31.8 (31 - 34, 1.3)	34.8 (29 - 41, 4.6)

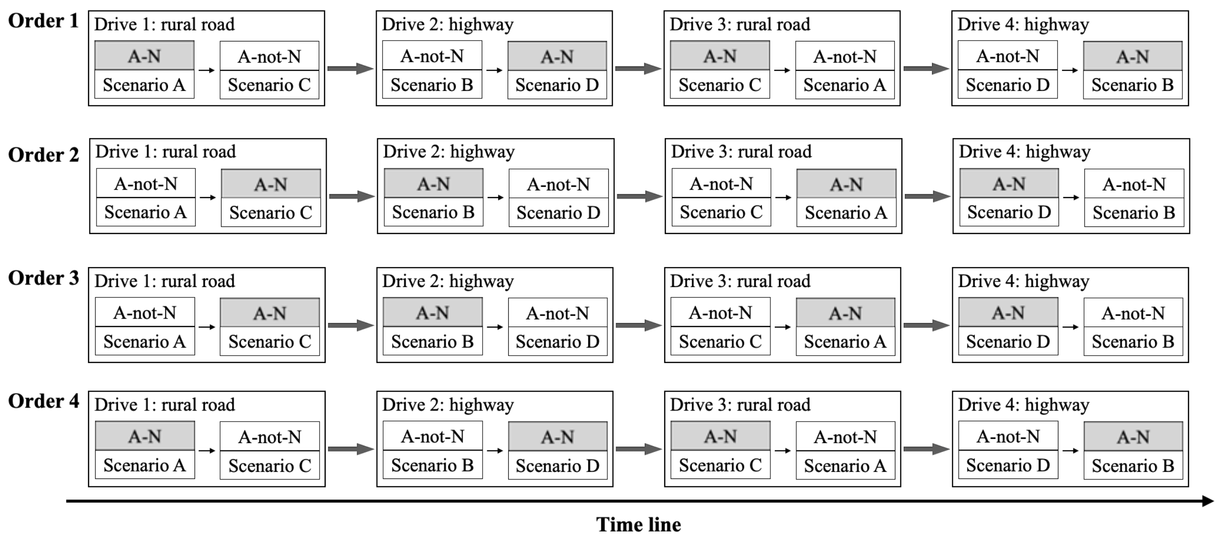
5.2.2 Participants

A total of 48 participants completed the experiment. This sample size was decided by the time and economic constraints, and also followed the same sample size as in the previous two experiments. Both novice and experienced drivers were recruited following the criteria in Chapter 2.2, i.e., experienced drivers had a full driver's license (G in Ontario or equivalent elsewhere in Canada or the U.S.) for at least 8 years, with > 20,000 km driven in the past year. Novice drivers obtained their first learners' license (G2 in Ontario or equivalent elsewhere in Canada or the U.S.) less than 3 years prior with < 10,000 km driven in the past year. The different combinations of experience and display type led to 6 distinct groups of participants, with 8 participants in each group, balanced for gender (i.e., 4 females and 4 males). Table 11 presents participants' age information across these between-subject factor levels. As expected, experienced drivers were older than novice drivers in general (mean difference = 13.0 years, $F(1,42)=86.69$, $p<.0001$), but as desired, there was no difference in the mean ages of drivers assigned to different types of displays, p=.9, and no interaction of experience and display type was found, p=.97. To make our participant sample representative of general driver population, participants were not filtered based on their experience with the ACC or LKA systems. However, the information of participants' experience with automation was collected in the screening questionnaire: 5 participants reported to use ACC only (5 of them used ACC less than once a year; and 1 used ACC several times a year), 3 participants to use LKA only (1 used LKA less than once a year; 1 used LKA several times a year; and the other one used LKA several times a month), and 8 participants to use both ACC and LKA (1 used ACC and LKA almost every day; 1 used ACC and LKA several times a month; 3 used ACC and LKA several times a year; 2 used ACC less than once a year and LKA several times a year; 1 used ACC several times a month and LKA almost every day).

5.2.3 Driving task

The driving automation implemented in the simulator consisted of ACC and LKA. Both systems could be engaged and disengaged using buttons on the steering wheel. Participants were instructed to use the automation (that is both ACC and LKA) as much as possible and were explained the limitations of the automation (see Chapter 2.3 and Chapter 5.2.5). They were also instructed to set the ACC speed at the speed limit and were told that safety was their first priority. On average, participants were found to use the ACC 91.2% of the time (SD: 4.5%) and LKA 97.2% of the time (SD: 2.4%).

There were four different scenario types used in the experiment (Scenarios A, B, C, D, Table 12), which were adapted from the ones used by previous studies (Stahl et al., 2014, 2016, 2019) and in previous two experiments. An A-N version and an A-not-N version of each scenario type were generated by manipulating the relative positions of the road agents (e.g., lead vehicles) and the ego-vehicle. Each participant completed four experimental drives (~5 minutes each), two of which were on a rural road and two of which were on a highway. The speed limit was 80.5 km/h (50 mph) for rural roads and 96.6 km/h (60 mph) for highways. There was moderate traffic on the opposite lanes, and one or two following vehicles that were far away from the ego-vehicle; there were no pedestrians. The surrounding vehicles that were not relevant to the anticipatory scenarios were programmed to move away from the ego-vehicle before the beginning of these scenarios. Participants were required to follow the lead vehicle and stay on the designated lane when possible, unless it was necessary to change lanes. Each drive had two anticipatory scenarios (one A-N and one A-not-N) that were designed to allow for the anticipation of an upcoming event. Thus, each participant experienced a total of 8 anticipatory scenarios in one of the four orders presented in Figure 18. Every two (one female and one male) out of the eight participants in each driving experience and display type combination underwent one of the four different orders.

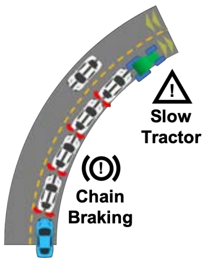
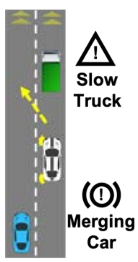


Note: Participants were assigned to one of four orders.

Figure 18. Order of anticipatory scenarios in Experiment 3

Similar to the scenarios used in the previous two experients, the beginning of an event (event onset) in each scenario was marked by an action of a lead or overtaking vehicle that would unambiguously indicate the upcoming event; e.g., a directional signal from the following vehicle in Scenario B as shown in Table 12. Anticipatory cues, in contrast, did not necessarily indicate a clear conflict. For example, again in Scenario B, the decreasing distance between the truck and the following vehicle can be considered an anticipatory cue suggesting that the following vehicle may merge left in front of the ego-vehicle; however, the following vehicle may also slow down and move to the left lane after the ego-vehicle passes.

Table 12. Description of the anticipatory driving scenarios used in Experiment 3

Scenario Image	Scenario Description
	*Scenario A: Chain Braking Event Due to Slow Tractor* Ego-vehicle followed a chain of four vehicles (in white) on a two-lane rural road with moderate oncoming traffic, traveling at 80.5 km/h (50 mph). The frontmost vehicle was $\boldsymbol{d_1}$ away from the ego-vehicle. Due to a slow tractor ahead on a curve, traveling at 40.2 km/h (25 mph), the front vehicle started to brake when within $\boldsymbol{d_2}$ of the tractor, with a deceleration of $\boldsymbol{a_1}$. The other lead vehicles braked consecutively. *Anticipatory cues*: slow tractor, reduced distance between lead vehicles, successive braking of lead vehicles (except the one directly ahead) *Event onset*: brake lights of the lead vehicle directly ahead of the ego-vehicle ***Action-necessary* version** • $\boldsymbol{d_1}$= 152.4 m (500 feet) • $\boldsymbol{d_2}$ = 61.0 m (200 feet) • $\boldsymbol{a_1}$ = 10 m/s^2 ***Action-not-necessary* version** • $\boldsymbol{d_1}$= 213.4 m (700 feet) • $\boldsymbol{d_2}$= 30.5 m (100 feet) • $\boldsymbol{a_1}$= 8 m/s^2
	*Scenario B: Merging Event Due to Slow Truck* Ego-vehicle traveled at 96.6 km/h on the left lane while driving on a four-lane divided highway. The ego-vehicle approached a truck and a following vehicle on the right lane, initially traveling at 72.4 km/h (45 mph). As the distance between the truck and the ego-vehicle fell under $\boldsymbol{d_1}$, the truck slowed down to be 36.1 km/h (22.4 mph) slower than ego-vehicle, forcing the following vehicle to slow down to be 10.8 km/h (6.7 mph) slower than the ego-vehicle. After about $\boldsymbol{t_1}$, the following vehicle signaled left and merged into the participant's lane with its speed $\boldsymbol{v_1}$ slower than the ego-vehicle, trying to pass the truck. About $\boldsymbol{t_2}$ seconds later, it accelerated to drive away after merging left. *Anticipatory cues*: reduced distance between the truck and the following vehicle *Event onset*: left signal of the merging vehicle ***Action-necessary* version** • $\boldsymbol{d_1}$= 79.0 m (260 feet) • $\boldsymbol{t_1}$ = 11 s • $\boldsymbol{v_1}$ = 24.1 km/h (15 mph) • $\boldsymbol{t_2}$ = 6 s ***Action-not-necessary* version** • $\boldsymbol{d_1}$= 92.2 m (302 feet) • $\boldsymbol{t_1}$ = 10 s • $\boldsymbol{v_1}$ = 8.1 km/h (5 mph) • $\boldsymbol{t_2}$ = 4 s
	*Scenario C: Merging Event Due to Coming Truck* The ego-vehicle followed a lead vehicle on a rural road. At a moment, the vehicle directly behind (overtaking vehicle) signaled left with high beams, pulled into the opposite lane, and accelerated to be $\boldsymbol{v_1}$ faster than the ego-vehicle to overtake the ego-vehicle. Because of a coming truck (relative speed of $\boldsymbol{v_2}$ to the ego-vehicle), the overtaking vehicle had to slow down to be 72.4 km/h (45 mph), cut in front of the ego-vehicle abruptly after signaling right, when the distance between the ego-vehicle and the truck fell under $\boldsymbol{d_1}$. The overtaking vehicle accelerated after merging right. *Anticipatory cues*: left signal and left merging of the overtaking vehicle, emerging of the coming truck *Event onset*: right signal of the overtaking vehicle ***Action-necessary* version** • $\boldsymbol{v_1}$ = 16.1 km/h (10 mph) • $\boldsymbol{v_2}$ = 144.8 km/h (90 mph) • $\boldsymbol{d_1}$ = 259.1 m (850 feet) ***Action-not-necessary* version** • $\boldsymbol{v_1}$ = 25.8 km/h (16 mph) • $\boldsymbol{v_2}$ = 136.8 km/h (85 mph) • $\boldsymbol{d_1}$ = 274.3 m (900 feet)

Scenario D: Chain Braking Event Due to Stranded Truck

The ego-vehicle was driving on the left of the highway. Because of a stranded truck and two police cars behind, two lead vehicles on the right lane were forced to brake in sequence with a deceleration of 5m/s^2, and merged left after signaling left, when the distance between the first lead vehicle on the right lane and the police car fell below $\boldsymbol{d_1}$. This forced the two lead vehicles on the left lane to brake. At this moment, the distance between the ego-vehicle and the lead vehicle directly ahead on the left lane was $\boldsymbol{d_2}$ and the lead vehicle was forced to brake for $\boldsymbol{t_1}$ with a deceleration of $\boldsymbol{a_1}$.

Anticipatory cues: the truck and the police vehicles becoming visible, the merging of two vehicles on the right, the braking of all other vehicles except the one directly ahead of the ego-vehicle, and the reducing distances between all vehicles except the distance between the ego-vehicle and the lead vehicle directly ahead.

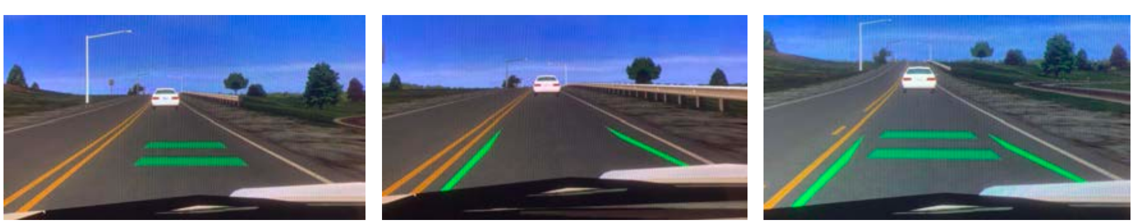
Event onset: brake lights of vehicle directly ahead

***Action-necessary* version**	***Action-not-necessary* version**
• $\boldsymbol{d_1}$ = 134.1 m (440 feet)	• $\boldsymbol{d_1}$ = 137.2 m (450 feet)
• $\boldsymbol{d_2}$ = 30.5 m (100 feet)	• $\boldsymbol{d_2}$ = 100.6 m (330 feet)
• $\boldsymbol{t_1}$ = 2.5 s	• $\boldsymbol{t_1}$ = 2 s
• $\boldsymbol{a_1}$ = 10 m/s^2	• $\boldsymbol{a_1}$ = 8 m/s^2

***Note**:* In the sketches, the ego-vehicle is blue; the truck or tractor is green; other vehicles are white except the police cars in Scenario D. The dashed yellow arrows show the potential paths of different road agents.

5.2.4 Display designs

Two types of displays designed for their effectiveness in supporting anticipatory driving in automated vehicles were investigated. The TORAC display provided TORs and automation capability (AC) information, while the STTORAC display provided TORs, automation capability information, and surrounding traffic (ST) information. These two displays were also evaluated against a baseline display that used static indicators overlaid on the road to inform the driver whether or not the ACC and LKA systems were engaged (as shown in Figure 19).



(a) (b) (c)

Figure 19. ACC and LKA states in baseline display in Experiment 3: (a) ACC is engaged; (b) LKA is engaged; (c) both ACC and LKA are engaged

5.2.4.1 TORAC: TOR + automation capability (AC) information

In the TORAC display design, ACC and LKA system capability information was presented using an augmented reality (AR) display on the windshield. Augmented reality displays have been shown to be effective in reducing response time to automation failures (Damböck et al., 2012; Debernard et al., 2016). TORs were provided through the same windshield displays visually; auditory warnings (three beeps provided 0.05 seconds apart at 4kHz, each around 0.05 seconds long) were also used as the auditory modality, which has been demonstrated to be more suitable than the visual modality for conveying high priority messages (Politis, Brewster, & Pollick, 2014; Walch et al., 2015). The braking distance of the ACC system was used to display the ACC capability, similar to Tonnis, Lange and Klinker (2007), and the visibility of lane markings was used to display LKA capability similar to implementations in production vehicles (e.g., Ford Motor Company, 2016). In the experiment reported in this chapter, the maximum deceleration of the ACC system in the ego-vehicle was 0.3g (~2.94 m/s2). Thus, it was possible that the ACC could not stop the vehicle in time to avoid a collision if a lead vehicle braked hard and at a close distance.

The display communicated the capability of the ACC to handle lead vehicle braking via horizontal bars overlaid on the road in front of the ego-vehicle. The participants were informed that there could be up to four bars presented to them. From the farthest bar to the closest, the bars represented the minimum safe gap distance if a lead vehicle were to brake at an infinitely large deceleration (sudden stop), a deceleration of 0.8g (~7.84 m/s^2), 0.6g (~5.88 m/s^2), and a deceleration of 0.4g (~3.92 m/s^2), going from the farthest bar to the closest bar. These deceleration rates were chosen based on how they were perceived in the simulator, going from intensive braking to slight braking. Figure 20a presents three of the four bars, meaning that the lead vehicle is at a gap distance where the ACC can respond safely if the lead vehicle is to brake at deceleration equal or less than 0.8g. When a lead vehicle braking event occurred, the green bars turned orange if the braking event could be handled by the ACC system without driver intervention (Figure 20b). However, if the ACC could not stop the vehicle safely, a TOR was issued, with the green bars turning red, and a "brake" icon appearing in the middle of the screen accompanied by an auditory warning requiring the driver to take over immediately (Figure 20c). The TOR was only triggered in action-necessary (A-N) scenarios, if the driver did not proactively intervene before event onset. For these situations, TOR was triggered at the moment the brake lights of the vehicle directly ahead were activated (Scenarios A and C), or when the following (Scenario B) or overtaking vehicles (Scenario D) started to cross the lane markings in front of the ego-vehicle.

To display the capabilities of the LKA system, two vertical bars were overlaid on the road parallel to the lane markings in front of the ego-vehicle (Figure 20d). The participants were told that the bars would turn red if no lane markings were detected, and the same auditory warning as used for ACC failure would be heard (Figure 20e), indicating that they would need to take over steering. Although participants were told that both systems could require their intervention, only critical events that could be anticipated based on the development of the traffic were focused on in this dissertation, and therefore, there were no situations where LKA had lane detection issues.

(a)

(b)

(c)

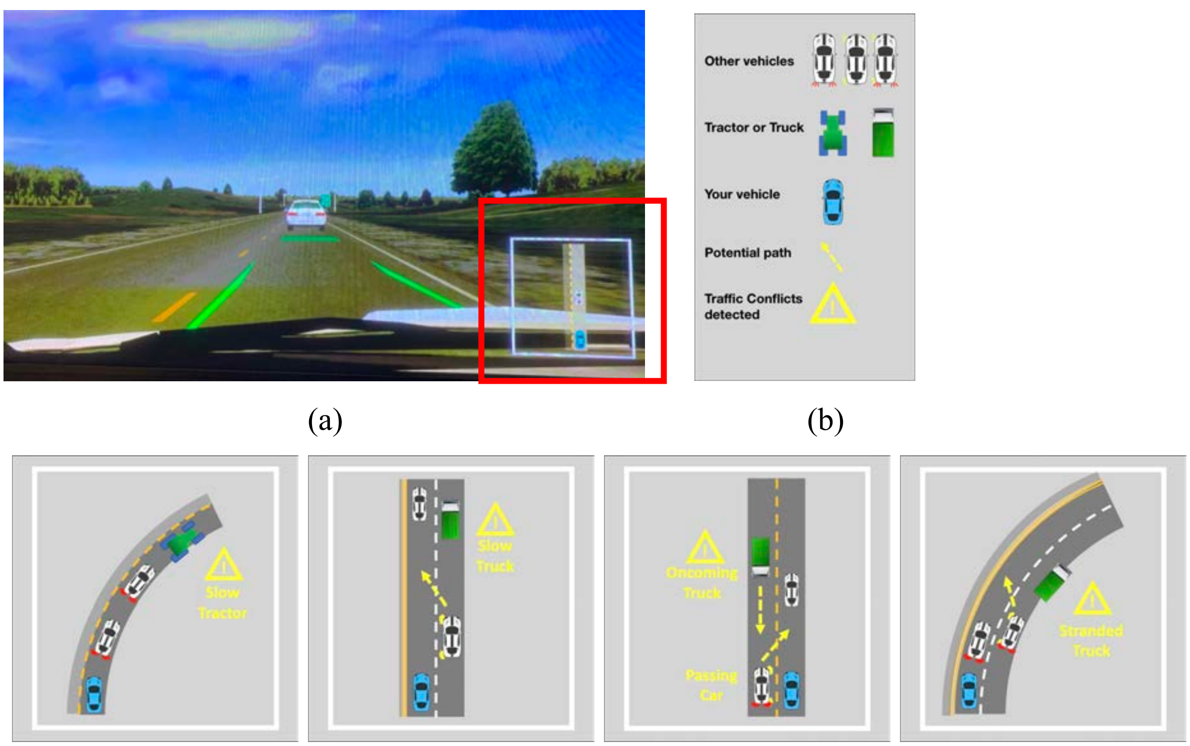
(d)

(e)

Figure 20. Automation capability information and visual component of TORs used in Experiment 3: (a) ACC indicators when there is no braking event and ACC can handle braking events with deceleration equal to or less than 0.8g (Four bars were visible if the ACC could handle a sudden stop of the lead vehicle, and fewer bars were visible if the ACC could handle only less intensive braking events); (b) ACC indicators when the lead vehicle brakes and ACC can handle the braking event; (c) ACC indicators and the visual component of the TOR when the ACC cannot handle a braking event; (d) LKA can detect lane markings; (e) visual component of the TOR when LKA cannot detect lane markings

5.2.4.2 STTORAC: Surrounding Traffic (ST) Information + TOR + Automation Capability (AC) Information

In addition to the TORAC display presented above, drivers in the STTORAC condition were also presented with a surrounding traffic information display (Figure 21) similar to what was used in Stahl et al. (2016). Through the use of ICV technologies, such a display can continuously present the relative positions of road agents (e.g., passenger vehicles, trucks, etc.) around the ego-vehicle, and can highlight any potential conflicts among other road agents, or between the ego-vehicle and other road agents, as well as potential paths that these agents may take. A limitation of the Stahl et al. (2016) study is that their displays appeared only when anticipatory cues for the events became visible to the driver, and thus drivers may have been reacting to the appearance of the display, rather than acting based on an understanding of the traffic information conveyed by the display. In the experiment reported in this chapter, the display showing the surrounding traffic information was available and was updated continually throughout the entire drive. It should be noted that in both the current study and in Stahl et al. (2016), the information on the surrounding traffic displays (e.g., GPS position and speed of surrounding vehicles, the road map and potential vehicle paths) was provided by the driving simulator software directly rather than through actual technologies such as GPS, and V2V and V2I communications. If implemented in actual vehicles on the road, such a display would heavily rely on such ICV technologies.



(c)

Figure 21. Surrounding traffic information display in Experiment 3: (a) Location of the display on the windshield (on the right bottom corner, as highlighted via a red rectangle in this figure); (b) Display legend presented to the participants during training (not presented while driving); (c) Surrounding traffic information for Scenarios A to D (from left to right)

Figure 21 shows the placement of the surrounding traffic display on the windshield, the different icons it used to convey traffic information, and images of how the scenarios described in Table 12 were presented on the display. It should be noted that to minimize clutter, the display represented an abstraction of the traffic situation and presented only the road agents that were relevant to the road conflicts and were visible to the drivers. It also presented traffic conflicts and potential vehicle paths.

5.2.5 Procedure

Upon participant arrival to the experiment session, the experimenter verified participant eligibility and obtained informed consent. The experimenter then introduced the participant to driving the simulator and performing the secondary task and asked the participant to practice the secondary task without driving the simulator. This was followed by the experimenter giving verbal instructions on the operation of the ACC and LKA systems, then asking the participant to practice operating them. During this training, the experimenter emphasized that the automated driving system may not be able to navigate some intense braking events because of the limited braking capability of the ACC, and that the LKA may not work when lane markings are faded or are missing. Then, participants completed a 10-minute practice drive, on a route similar to the ones in the experimental drives in terms of traffic density and road type, but without any in-vehicle displays or anticipatory driving scenarios. For the first 5 minutes of this practice drive, participants were required to drive the vehicle without automation; after 5 minutes, they were instructed to engage and disengage the ACC and LKA twice and then keep using these systems until they felt comfortable driving with them. Participants were also required to practice interacting with the secondary task during this practice drive. Before this practice drive, participants were informed about simulator sickness and were asked to indicate in case they experienced any of its symptoms. The experimenter also monitored the participants for signs of sickness. No cases of simulator sickness were observed.

Participants were then introduced to the automation displays based on the condition they were assigned to (i.e., baseline, TORAC, or STTORAC), and performed another practice drive to familiarize themselves with the displays. Next, participants completed one more practice drive, but they were told that this was an experimental drive, to minimize their ability to figure out the purpose of the study. This additional practice drive included two abrupt-onset braking events (sudden lead vehicle braking events) that were not designed to elicit anticipatory behaviors. One of the braking events was A-N, i.e., it required the participant to take over vehicle control to avoid a collision. This additional drive aimed to improve participants' understanding of the automation's capabilities, based on the premise that experiencing transfers of control from the automation, as compared to verbal instructions only, can better calibrate drivers' trust in and reliance on the automation (Körber et al., 2018). In this practice drive and the following experimental drives, participants were asked to prioritize driving safety, to use ACC and LKA as much as possible, and to take over the control of the vehicle only when necessary. Further, in this last practice drive and all experimental drives, participants were told to set the cruise speed of the ACC at the speed limit, and keep driving on either the left or the right lane, unless it was necessary to change lanes (see Appendix U for detailed instructions). After these practice drives, participants completed the four experimental drives. After each experimental drive, participants were asked to respond to questionnaires as described in detail in Table 2. They also finished a post-experiment questionnaire after all experimental drives, as also described in Table 2.

5.2.6 Dependent variables and statistical analysis

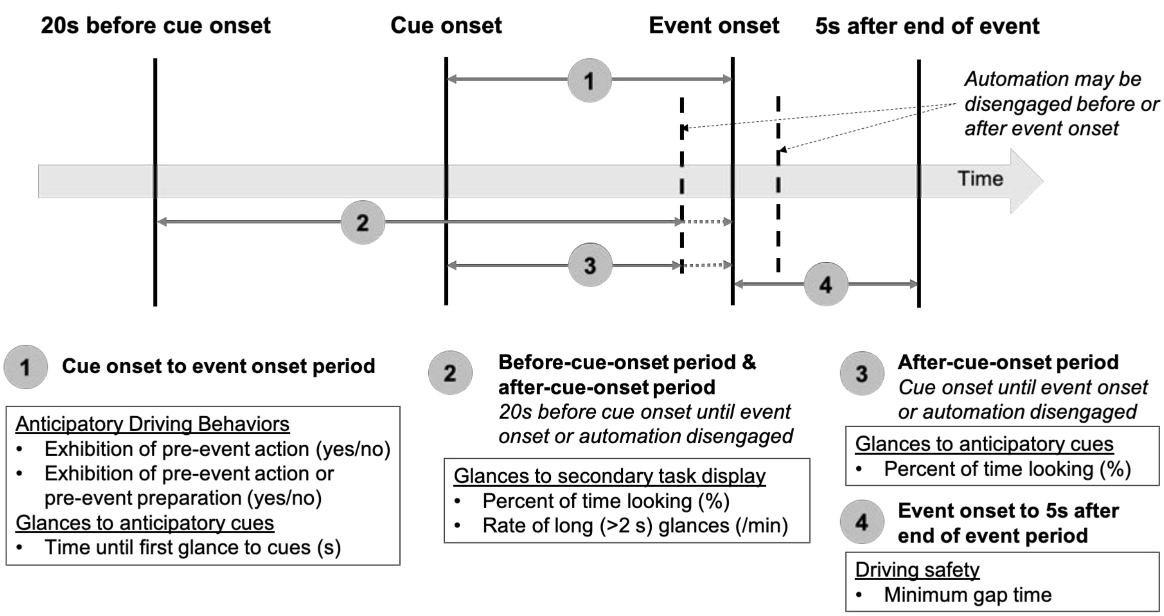
Four categories of variables were analyzed:

- Whether the participant exhibited anticipatory driving behaviors,
- Measures of glance behaviors to anticipatory cues and secondary task display,
- Minimum gap time during an event as a driving safety measure,
- Questionnaire responses on perceived workload, trust, and acceptance.

For the identification of anticipatory driving behaviors, whether drivers performed any pre-event actions was investigated, i.e., control actions performed prior to the event onset in anticipation of an event, in a manner similar to anticipatory driving behavior identification in non-automated vehicles (Stahl et al., 2014, 2016). For the automated vehicle context, pre-event actions were operationalized as actions the driver performed before an event onset to take over the control of the vehicle or to change the settings of the automation. The possible pre-event actions included control actions aimed to slow down the vehicle for all scenarios (i.e., disengaging the ACC by pressing the brake pedal or the cancel button, or reducing the set speed of the ACC system through buttons on the steering wheel), or speed up the vehicle for Scenarios B and C (i.e., pressing the gas pedal or increasing the set speed of the ACC system through steering wheel buttons). In addition to pre-event actions, pre-event preparation was considered as another type of anticipatory driving behavior when a pre-event action was not performed. Pre-event preparation was defined as an observed intention by the drivers to intervene in the driving task before event onset, for example, by moving their foot toward the brake or accelerator pedals, moving their hands toward the steering wheel, or hovering their finger above one of the control buttons that could disengage the automation or adjust its settings (e.g., ACC speed).

Three raters blind to the participants' level of driving experience used the videos of the forward view, the driver's feet, and the driver's hands to independently judge whether the participants exhibited any anticipatory driving behaviors (pre-event action or pre-event preparation) in a given scenario. One rater was the author of this dissertation and other two raters were different from the ones in Experiment 1 and Experiment 2. One rater had 10 years of driving experience, one had 3 years of driving experience, and the other had no driving experience. The raters were trained on the concept of anticipatory driving and the possible anticipatory driving behaviors the participants could exhibit in each scenario. The raters were not provided with strict criteria; instead, they were asked to make their own judgement. Conflicts were resolved by asking the raters to re-watch the recorded data (videos and eye-tracking data) and discuss their findings. The raters reached a substantial inter-rater reliability, Fleiss' $k=0.73$, $z=24.93$, $p<.05$, before resolving the conflicts. Finally, for cases where a pre-event action or a pre-event preparation was identified, if the driver exhibited no glances toward any of the anticipatory cues before event onset, then these cases were re-categorized as no action and no preparation. This was done to avoid including coincidental foot or hand movements as anticipatory driving behaviors.

According to the ISO 15007-1:2014(E) standard (International Organization for Standardization, 2014), a glance was defined as initiating at the moment when the direction of gaze started to move toward an area of interest (e.g., secondary task display) and ending at the moment when it started to move away from it. The glance measures used in the analysis are listed in Figure 22; cue onset refers to the moment when the first anticipatory cue became visible. It should be noted that if a participant never looked at a cue, the time until first glance was regarded as the duration from the cue onset to the event onset. Glances that fell partially on a data extraction period were handled following the method in Seppelt et al. (2017). Two seconds was used as the threshold for long glances based on crash risk research conducted in non-automated driving (Klauer et al., 2006) as no equivalent threshold exists for automated driving. In addition to the glance measures listed in Figure 22, mean glance duration and rate of glances at the anticipatory cues and at the secondary task were analyzed (see Appendix V) but are not reported in this chapter, as these measures did not provide any additional insights and because drivers' visual attention allocation could be explained using primarily the variables listed in Figure 22. It should also be noted that although the number of cues was different across the four scenario types, this did not affect the analysis as comparisons across scenario types are not of interest in this dissertation.



Note: The mean duration of the after-cue-onset period was 36.6 sec (SD: 5.5) for Scenario A, 10.4 sec (SD: 1.2) for Scenario B, 9.6 sec (SD: 1.5) for Scenario C, and 13.0 sec (SD: 3.2) for Scenario D. The duration from event onset to end of event was 4 sec for Scenario A, Scenario C, and A-not-N version of Scenario B, 6 sec for A-N version of Scenario B, 2 sec for A-not-N version of scenario D, and 2.5 sec for A-N version of Scenario D.

Figure 22. Time periods used to extract anticipatory driving, glance, and driving safety measures in Experiment 3

The minimum gap time during an event was extracted from the "event onset to 5s after end of event" period, where the "end of event" was the moment the braking or merging vehicle accelerated to drive away in each scenario. Overall, there were only 17 collisions in a total of 384 scenarios; thus collisions were not analyzed but were captured in the calculation of minimum gap time, with the value of 0 marking a collision. In a collision, participants received only visual feedback: the ego-vehicle overlapped with the other vehicle for a brief period.

All statistical models were built in SAS University Edition V9.4. In addition to the analysis of independent variables that were part of the experiment design (i.e., experience, display type, and scenario criticality), one more independent variable, "cue-onset", was created to investigate whether drivers' behavior changed as cues became visible. The "cue-onset" variable had two levels: before-cue-onset (i.e., the period from 20 seconds prior to cue onset until cue onset) and after-cue-onset (i.e., the period from cue onset to event onset or automation disengaged, whichever was earlier). Binary dependent variables (e.g., whether drivers exhibited pre-event actions) were analyzed using logistic regression models. The rate of long (>2s) glances toward the secondary task was analyzed using a negative binomial model given that over-dispersion (variance: 2.98 > mean: 1.83) was detected; the length of the data extraction period (i.e., before-cue-onset and after-cue-onset periods) was used as the offset variable. The repeated measures (i.e., four scenarios for each participant) in the logistic regression and the negative binomial models were accounted for using generalized estimating equations. All other variables were analyzed using linear mixed models, with participant introduced as a random factor and with compound symmetry variance-covariance structure. Dependent variables were transformed when necessary to satisfy mixed model assumptions. Significant main and interaction effects were followed by pairwise comparisons; only the significant ($p<.05$) pairwise comparisons are reported in the results section.

5.3 Results

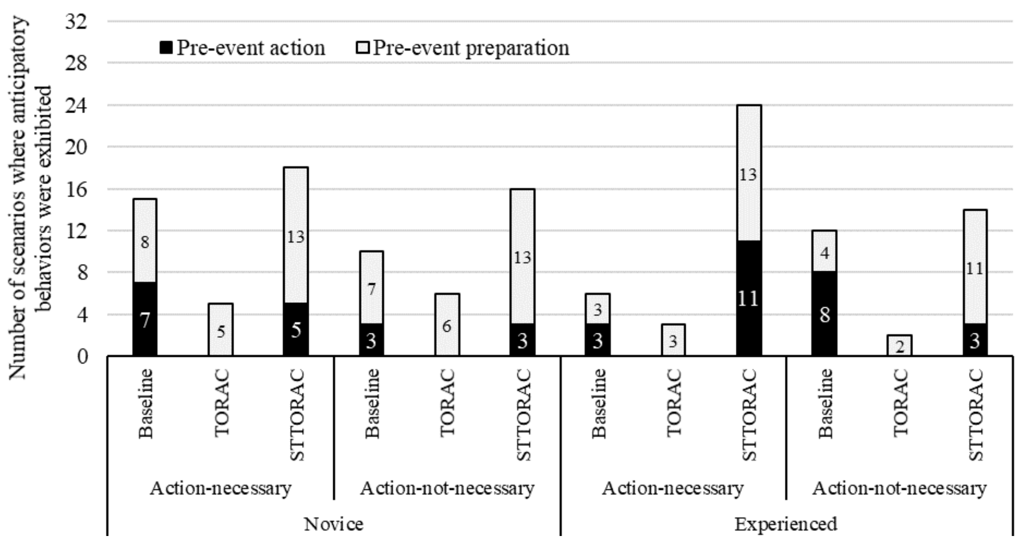
5.3.1 Anticipatory driving behaviors

The statistical results from the models built to analyze pre-event actions and anticipatory driving behaviors can be found in Table 13. Drivers experiencing the TORAC display (TOR and automation capability information) did not exhibit any pre-event actions in any of the anticipatory driving scenarios (see Figure 23). Thus, a model was built to compare the odds of performing pre-event actions when drivers were provided with the STTORAC display (TOR, automation capability, and surrounding traffic information) versus the baseline display, and no significant effects were observed. A significant display effect was observed when the dependent variable was exhibiting anticipatory driving in general (pre-event action or pre-event preparation) vs. not exhibiting any: the odds of exhibiting anticipatory driving behaviors was the highest with the STTORAC display, followed by the baseline, and then the TORAC display (STTORAC vs. baseline: Odds Ratio (OR)=2.58, 95% CI: 1.29, 5.16, $\chi2(1)$= 7.17, p=.007; STTORAC vs. TORAC: OR=9.77, 95% CI: 3.40, 28.04, $\chi2(1)$=17.94, p<.0001; baseline vs. TORAC: OR=3.79, 95% CI: 1.41, 10.22, $\chi2(1)$=6.93, p=.009).

Table 13. Statistical results for anticipatory driving behavior models in Experiment 3: The main and interaction effects are reported.

Dependent Variables	**Independent Variables and Interactions**	**df**	χ^2	***p***
Pre-event action vs. No pre-event action	Display **(STTORAC vs. Baseline only)**	1	0.18	.67
	Experience	1	1.32	.25
	Scenario criticality	1	2.25	.13
	Experience*Display	1	0.83	.36
	Experience*Scenario criticality	1	0.93	.33
	Scenario criticality*Display	1	3.51	.06
Anticipatory driving behavior (Pre-event action or pre-event preparation) vs. No anticipatory driving behavior	Display	2	18.95	<.0001*
	Experience	1	0.96	.33
	Scenario criticality	1	0.79	.37
	Experience*Display	2	1.57	.46
	Experience*Scenario criticality	1	0.01	.90
	Scenario criticality*Display	2	3.30	.19

Note: * p<.05.



Note: The total number of scenarios for each experimental condition is 32 (8 participants per condition who experienced 4 scenarios for a given level of scenario criticality). Each bar represents the number of scenarios where pre-event actions or pre-event preparations were observed under each experimental condition.

Figure 23. Number of scenarios where anticipatory driving behaviors were exhibited in Experiment 3

5.3.2 Glance behaviors

The statistical results for glance models are presented in Table 14. As also demonstrated in Figure 24a and Figure 24b, the TORAC display led to a longer time until first glance and lower percent of time looking at cues compared to both STTORAC ($t(42)=4.42$, $p<.0001$ and $t(42)= -4.39$, $p<.0001$) and baseline displays ($t(42)=2.89$, $p=.006$ and $t(42)= -3.37$, $p=.002$).

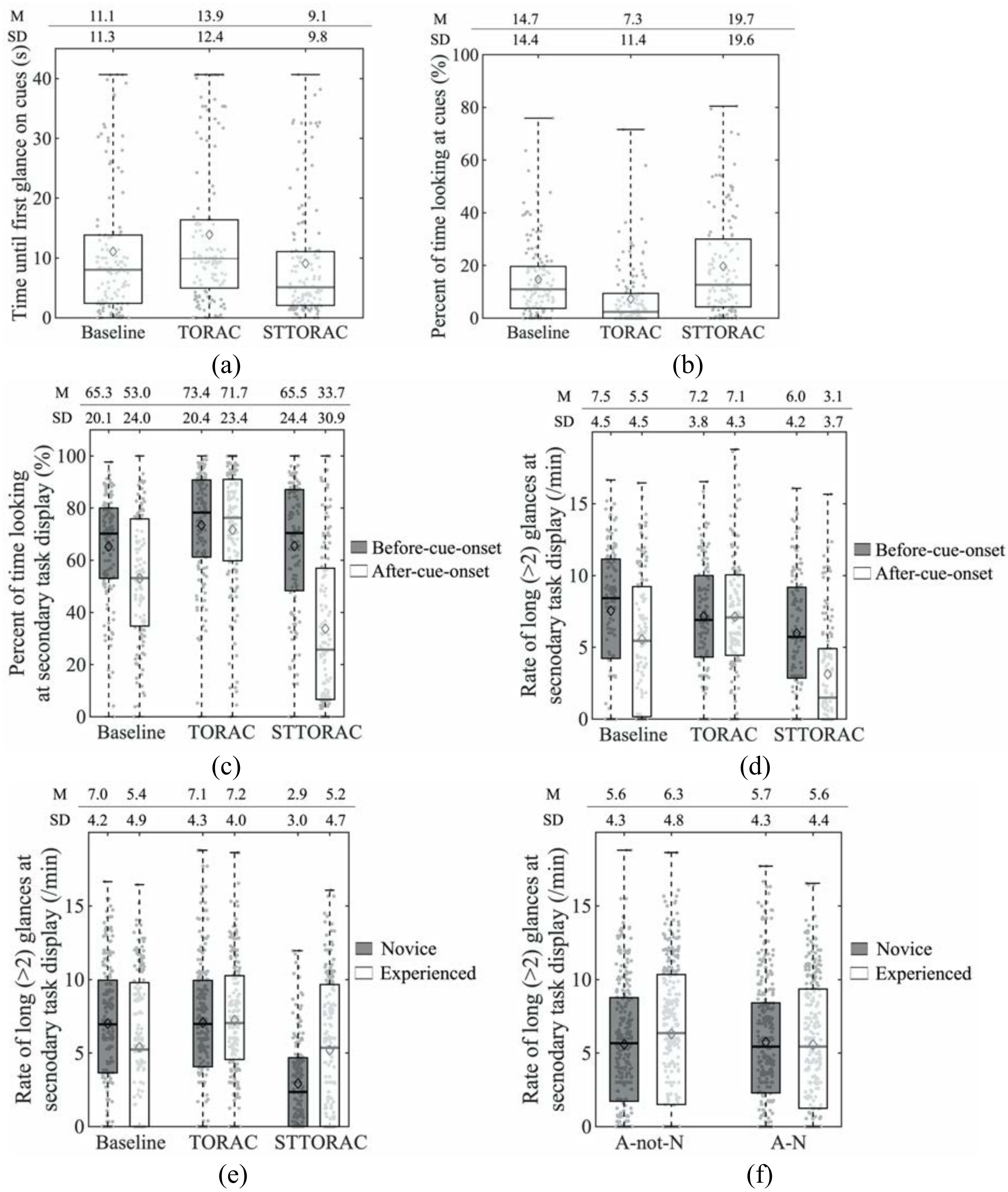
Interaction effects were found between display type and cue-onset for the percent of time spent looking at (Figure 24c) and rate of long glances toward the secondary task (Figure 24d). Specifically, it was found that with both the STTORAC and the baseline displays, both measures decreased from before cue-onset to after cue-onset (*percent of time*: $t(711)= -13.69$, $p<.0001$ for STTORAC and $t(711)= -5.30$, $p<.0001$ for baseline; *rate of long glances*: $\chi^2(1)=15.13$, $p<.0001$ for STORRAC and $\chi^2(1)=21.05$, $p<.0001$ for baseline). In the after-cue-onset period, percent time looking at the secondary task was highest for TORAC, followed by baseline, and then STTORAC (*TORAC vs. baseline*: $t(48.5)=3.01$, $p=.004$; *TORAC vs. STTORAC*: $t(48.5)=6.11$, $p<.0001$; *baseline vs. STTORAC*: $t(48.5)=3.10$, $p=.003$). Similarly, compared to STTORAC, TORAC resulted in a higher rate of long glances to the secondary task in the after-cue-onset period, $\chi^2(1)=9.19$, $p=.002$.

Experience was found to interact with display type (Figure 24e) as well as scenario criticality (Figure 24f) for rate of long glances. Novice drivers had lower rates of long glances to the secondary task compared to experienced drivers when provided with the STTORAC display, $\chi^2(1)=4.17$, $p=.04$. Further, novice drivers had lower rates of long glances to the secondary task display when provided with the STTORAC display compared to baseline, $\chi^2(1)=12.71$, $p=.0004$, and the TORAC display, $\chi^2(1)=6.18$, $p=.01$. Further, experienced drivers had lower rates of long glances toward the secondary task in A-N scenarios compared to A-not-N scenarios, $\chi^2(1)=10.35$, $p=.001$.

Table 14. Statistical results for glance and driving safety models in Experiment 3

	Dependent Variables									
	Visual attention to cues				Visual attention to secondary task display				Driving safety	
	Time until 1st glance		% of time looking		% of time looking		Rate of long glances		Minimum gap time	
Independent Variables	*F*-value	*p*	*F*-value	*p*	*F*-value	*p*	χ^2-value	*p*	*F*-value	*p*
Display	F(2,42)=10.08	.0003*	F(2,42)=10.57	.0002*	F(2,42)=7.40	.002*	$\chi^2(2)=3.86$	.15	F(2,40.5)=5.41	.008*
Experience	F(1,42)=0.44	.51	F(1,42)=0.02	.89	F(1,42)=0.18	.67	$\chi^2(1)=0.06$	.80	F(1,40.5)=1.44	.24
Scenario criticality	F(1,332)=1.20	.28	F(1,332)=0.17	.68	F(1,711)=0.11	.74	$\chi^2(1)=0.49$	.48	F(1,326)=207.7	<.0001*
Cue-onset	-	-	-	-	F(1,711)=129.7	<.0001*	$\chi^2(1)=28.26$	<.0001*	-	-
Experience*Display	F(2,42)=0.40	.67	F(2,42)=0.14	.87	F(2,42)=0.30	.74	$\chi^2(2)=7.14$	.03*	F(2,40.5)=3.35	.045*
Experience*Scenario criticality	F(1,332)=1.26	.26	F(1,332)=0.96	.33	F(1,711)=1.39	.24	$\chi^2(1)=8.46$	.004*	F(1,326)=0.46	.50
Experience*Cue-onset	-	-	-	-	F(1,711)=0.12	.73	$\chi^2(1)=0.70$	.40	-	-
Scenario criticality*Display	F(2,332)=0.40	.67	F(2,332)=0.32	.73	F(2,711)=0.19	.83	$\chi^2(2)=0.69$	.71	F(2,326)=8.11	.0004*
Scenario criticality*Cue-onset	-	-	-	-	F(1,711)=0.62	.43	$\chi^2(1)=1.14$	.28	-	-
Display*Cue-onset	-	-	-	-	F(2,711)=43.14	<.0001*	$\chi^2(2)=19.64$	<.0001*	-	-
Gap distance at event onset	-	-	-	-	-	-	-	-	F(1,328)=22.27	<.0001*

Note: * p<.05; The first column lists the independent variables investigated in the analysis and their interactions; the other columns present the statistical results for different dependent variables. A dash ("-") indicates that the corresponding independent variable was not applicable for that measure and was not included in its statistical analysis (e.g., cue-onset is not a relevant variable for analyzing % time looking at cues; this measure has a value of zero before cue-onset).

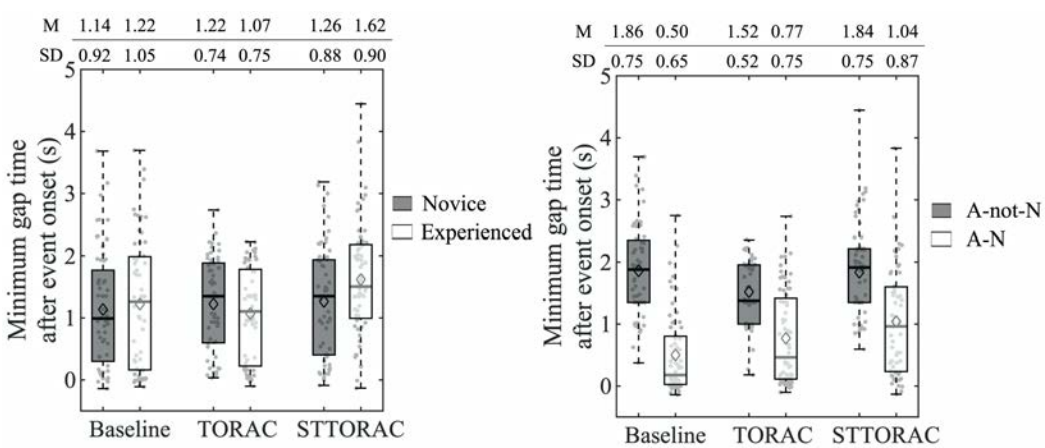


Note: Boxplots present the minimum, 1st quartile, median, 3rd quartile, and maximum, along with the mean depicted through a hollow diamond. The mean (M) and standard deviation (SD) values are also provided at the top of each plot.

Figure 24. Boxplots of visual attention measures representing significant main and interaction effects in Experiment 3: (a) time until first glance at cues by display, (b) percent of time looking at cues by display, (c) percent of time looking at secondary task display for display and cue-onset interaction, (d) rate of long glances at secondary task display for display and cue-onset interaction, (e) rate of long glances at secondary task display for display and experience interaction, and (f) rate of long glances at secondary task display for experience and scenario criticality interaction

5.3.3 Driving safety

For minimum gap time (Figure 25), display type was found to interact with experience and scenario criticality. Experienced drivers had a longer minimum gap time with the STTORAC compared to the TORAC, mean difference (Δ)=0.57 sec, t(40.8)=3.97, p=.0003, 95% CI: 0.28, 0.86, and the baseline displays, Δ=0.40 sec, t(41.6)=2.80, p=.008, 95% CI: 0.11, 0.69. Further, experienced drivers had a longer minimum gap time than novice drivers with the STTORAC display, Δ=0.37 sec, t(40.8)=2.56, p=.01, 95% CI: 0.08, 0.65. A-not-N scenarios led to higher minimum gap times than A-N scenarios for all displays (*baseline*: Δ=1.43 sec, t(326)=11.64, p<.0001, 95% CI: 1.19, 1.67; *TORAC*: Δ=0.81 sec, t(326)=6.64, p<.0001, 95% CI: 0.57, 1.04; *STTORAC*, Δ=0.85 sec, t(326)=6.97, p<.0001, 95% CI: 0.61, 1.09). In A-N scenarios, the STTORAC display led to the longest minimum gap times, followed by TORAC, and then the baseline displays (*STTORAC vs. TORAC*: Δ=0.28 sec, t(113)=2.14, p=.03, 95% CI: 0.02, 0.55; *STTORAC vs. baseline*: Δ=0.55 sec, t(114)=4.14, p<.0001, 95% CI: 0.29, 0.81; *TORAC vs. baseline*: Δ=0.27 sec, t(113)=2.02, p=.046, 95% CI: 0.004, 0.53), while in A-not-N scenarios, both the STTORAC and the baseline displays led to longer minimum gap times compared to the TORAC display (*baseline*: Δ=0.35 sec, t(113)=2.68, p=.008, 95% CI: 0.09, 0.62, *STTORAC*: Δ=0.33 sec, t(113)=2.50, p=.01, 95% CI: 0.07, 0.59).



(a) (b)

Figure 25. Boxplots of minimum gap time representing significant interaction effects in Experiment 3: a) by display type and driving experience, b) by display type and scenario criticality

5.3.4 Subjective responses

Display type influenced the perceived usefulness of, $F(2,42)=4.43$, $p=.02$, and the satisfaction with, $F(2,42)=5.48$, $p=.008$, the automation. The automation with TORAC display was perceived as more useful and more satisfactory compared to the automation with the baseline display, (*usefulness*: $\Delta=0.70$, 95% CI: 0.22, 1.18, $t(42)=2.97$, $p=.005$; *satisfying*: $\Delta=0.78$, 95% CI: 0.30, 1.27, $t(42)=3.24$, $p=.002$), and more satisfactory compared to the automation with the STTORAC display ($\Delta=2.11$, 95% CI: 0.17, 4.05, $t(42)=2.19$, $p=.03$). Display type also had a significant effect on trust, $F(2,42)=6.96$, $p=.002$. Both the TORAC display, $\Delta=1.59$, 95% CI: 0.73, 2.46, $t(42)=3.71$, $p=.0006$, and the STTORAC display, $\Delta=0.94$, 95% CI: 0.07, 1.80, $t(42)=2.18$, $p=.03$, led to higher self-reported trust in the automated driving system compared to the baseline display. No significant effects of driving experience, display type, or their interactions were observed for the perceived workload ($p>.05$). The average scores of NASA-TLX were 40.3 (SD: 21.1), 31.2 (SD: 17.5), and 34.5 (SD: 23.0) for the baseline, TORAC, and STTORAC displays, respectively.

5.4 Discussion

In this driving simulator study, the effectiveness of two types of displays for supporting anticipatory driving in automated vehicles was investigated. The TORAC display, which provided a takeover request (TOR) along with automation capability (AC) information, was similar to those used in previous studies and found to be effective in supporting drivers during takeover events (e.g., Gold, Damböck, Bengler, et al., 2013; Seppelt & Lee, 2007; Tonnis et al., 2007). The STTORAC display incorporated the information conveyed by the TORAC display with additional information regarding the surrounding traffic environment. Display elements representing surrounding traffic information were adapted from a display evaluated in a previous study on supporting anticipatory driving in non-automated vehicles (Stahl et al., 2016). The surrounding traffic information conveyed in these displays can be made available through ICV technologies. Both displays were evaluated against a baseline display that showed only whether the automation (ACC and LKA) was engaged.

It was found that the STTORAC display resulted in the highest likelihood of anticipatory driving behaviors (including pre-event action and pre-event preparation); it also resulted in the longest minimum gap time in scenarios where a control action by the driver was necessary to avoid a collision (that is, action-necessary scenarios). These findings suggest that providing surrounding traffic information in an automated driving context supports drivers' anticipation of events in the environment and enhances the quality of their responses to critical events. The TORAC display, in contrast, resulted in the lowest likelihood of anticipatory driving behaviors compared to both the STTORAC and the baseline displays. However, the TORAC display still showed some benefit in terms of driving safety in scenarios where driver intervention was necessary: there was an increase in minimum gap time compared to the baseline display.

An examination of drivers' glances at the anticipatory cues provided further insights on how each display impacted anticipatory driving. Drivers were the slowest with the TORAC display to direct their visual attention (longest time until first glance) to anticipatory cues and paid the least attention to them (lowest percent of time looking at cues). This aligns with previous findings from Experiment 1 and previous research in non-automated driving (Stahl et al., 2019), which revealed a positive association between visual attention to anticipatory cues and anticipatory driving behaviors. No significant difference was found between the STTORAC and the baseline displays in terms of visual attention to anticipatory cues, yet, the STTORAC display led to an increase in anticipatory driving behaviors compared to the baseline display. Thus, the exhibition of anticipatory driving behaviors depends on more than just cue perception and appears to be supported by a combination of display elements.

TORs and automation capability displays have been proposed and evaluated in previous research to support takeover performance in automated driving systems (Seppelt & Lee, 2007; Walch et al., 2015). The results in this current chapter indicate that drivers provided with TORs along with automation capability information (TORAC display) may develop overreliance on automation, whereas providing surrounding traffic information along with TORs and automation capability information (STTORAC display) seems to resolve this issue of possible overreliance. Both STTORAC and TORAC displays led to higher trust in automation compared to the baseline display, with the TORAC display rated as more useful and more satisfying than the STTORAC display. However, the TORAC display resulted in the highest level of engagement in the secondary task as indicated by percent time looking. Further, as stated earlier, the TORAC display had the lowest likelihood of anticipatory driving behaviors. In fact, drivers with the TORAC display did not exhibit any pre-event actions and some only intervened after a TOR was provided, even though they showed some preparation before the TOR (pre-event preparation), implying that they may have realized potential conflicts but chose not to act on them until a TOR was issued. These findings suggest that drivers with the TORAC display may have assigned more "responsibility" to the automation, while those who received additional surrounding traffic information (through the STTORAC display) developed a better understanding of the traffic situation and thus more appropriate reliance. Although in the study TORs were 100% reliable, they would not be so in reality, and over-relying on the driving automation to monitor the environment and provide a TOR when the driver action is needed would lead to safety issues. Workload associated with monitoring the roadway and the automation can be seen as a potential reason as to why drivers may have assigned more responsibility to the TORAC display than they did to the other two displays. However, no differences in perceived workload across the different experimental conditions were observed. Further, the magnitude of the NASA-TLX responses did not indicate information overload associated with any of the conditions, although the response variance was relatively high. Thus, further data is needed to test the relation between perceived workload and reliance on vehicle automation.

Driving experience was found to interact with display type and with scenario criticality. When provided with the STTORAC display, experienced drivers had longer minimum gap time compared to novice drivers, even though they had spent a higher percent of time looking at the secondary task and had a higher rate of long (>2s) glances at it. A possible explanation for these differences is that more experienced drivers developed a better and quicker understanding of the traffic information presented in the STTORAC display, and thus were able to exhibit safer driving behaviors despite engaging with the secondary task more. Experienced drivers also appeared to adapt their secondary task engagement based on scenario criticality, having a reduced rate of long (>2s) glances toward the secondary task in scenarios where their intervention was necessary compared to those that the automation could handle. This result aligns with findings of Underwood (2007), indicating that experienced drivers can adapt their visual scanning behaviors more effectively than novice drivers based on the complexity of the traffic environment.

The way the anticipatory driving was studied in this study was by investigating observable behaviors, and thus did not capture drivers who may have anticipated conflicts but chose not to physically act or prepare for them. The study cannot reveal why some drivers chose to act whereas others showed preparation without intervening with the automation. Future work can incorporate measures on risk perception and tolerance along with other individual differences that may further explain differences in driver response. Further, as stated above, the displays that were evaluated (e.g., TORs) were 100% reliable and the participants in this experiment experienced these displays only for a short period of time. More research is needed to identify whether the findings from this study would hold true with long-term use and when drivers experience display failures. Lastly, only limited types of scenarios were adopted in this study. Future research should consider validating the findings in a wider variety of anticipatory driving scenarios.

It should also be noted that the automated driving systems (ACC and LKA) studied in this experiment corresponded to SAE level 2 automation (SAE On-Road Automated Vehicle Standards Committee, 2018), and further research is needed to extend these findings to higher levels of driving automation. Although the use of TORAC and STTORAC displays might indicate an implementation of SAE Level 3 automation, the TOR implemented in this experiment was not issued in advance of the braking or merging events, and thus would still require the drivers to monitor the roadway. So even with the TORAC or STTORAC displays, the driving automation implemented in this experiment cannot be categorized as SAE Level 3, although the displays may create a system more advanced than the Level 2 systems currently in use. This also points to limitations in the SAE taxonomy of levels of driving automation, particularly in relation to SAE Level 3, or conditional driving automation, as also discussed by other authors (e.g., Biondi, Alvarez, & Jeong, 2019; Inagaki & Sheridan, 2019).

Chapter 6

6 Summary and Conclusions

6.1 Summary of key findings

NON-AUTOMATED VEHICLES:

- Anticipatory driving behaviors (or, specifically, pre-event actions) were found to be more prevalent among experienced drivers compared to novices, similar to what has been found in previous research. As a novel finding, it was found that distractions, in particular visual-manual distractions, reduced the likelihood of exhibiting anticipatory driving behaviors in non-automated vehicles.
- Visual attention to anticipatory cues was found to be positively associated with the likelihood of exhibiting anticipatory driving behaviors in non-automated vehicles. Experienced drivers allocated more visual attention to anticipatory cues than novices, and visual-manual distraction reduced visual attention to anticipatory cues for both novice and experienced drivers in non-automated vehicles. Further, although the likelihood of exhibiting anticipatory driving behaviors could be predicted by mean on-road glance duration, a better prediction was obtained by also considering mean glance duration on cues. Thus, in addition to how long drivers are looking at the road, how long they are looking at anticipatory cues before traffic conflicts materialize may be an essential determinant of proactive actions.
- Although both novice and experienced drivers reduced their distraction engagement as anticipatory cues became visible, experienced drivers, in general, appeared to have better visual scanning strategies in the presence of distraction as evidenced by spending more time looking at anticipatory cues on the road and a lower likelihood of exhibiting long off-road glances .

AUTOMATED VEHICLES (with ACC and LKA):

- The definition of anticipatory driving behavior was extended to capture both pre-event actions (similar to what was defined in non-automated vehicles) and pre-event preparation in automated vehicles. It was found that experienced drivers showed more anticipatory driving behaviors than novice drivers, and visual-manual distractions impeded anticipatory driving behaviors in automated vehicles.

- However, unlike in non-automated vehicles, although the presence of a visual-manual distraction was associated with a lower percentage of time looking at anticipatory cues and a longer time to first glance at cues, experienced drivers (who showed more anticipatory driving behaviors compared to novice drivers in automated vehicles) did not glance more at anticipatory cues compared to novice drivers, indicating that the monitoring of cues alone may not explain the difference in the performance of anticipatory driving in automated vehicles. Drivers' perceived usefulness of, trust in, and reliance on the automated driving systems may also play a role.
- Two in-vehicle displays to support driver anticipation in automated vehicles were explored. It was found that the TORAC display (with takeover request and automation capability information, which has been widely explored in previous automated driving research) impeded anticipation in automated vehicles. In contrast, the STTORAC display (with surrounding traffic information in addition to the information in TORAC display) facilitated anticipation in driving. Considering that drivers with TORAC display allocated most visual attention on secondary tasks after cue onset and did not exhibit any pre-event actions (though some intervened after a TOR was provided) compared with drivers in the baseline, drivers with the TORAC display may have assigned more "responsibility" to the automation. In other words, they may have relied more on the automation. At the same time, drivers who received additional surrounding traffic information (through STTORAC display) developed a better understanding of the traffic situation and thus more appropriate reliance on automated driving systems. These results further supported the association between reliance on automation and anticipatory driving behaviors.

6.2 Contributions

Driving safety in automated vehicles highly relies on drivers' ability to take over vehicle control in case of emergencies, at least until fully automated vehicles become a reality (SAE On-Road Automated Vehicle Standards Committee, 2018). The complex traffic environment on the road can lead to situations that exceed the capabilities of the automation and thus require drivers' intervention. Previous research in automated vehicles has investigated drivers' behaviors in a variety of situations (see Appendix B), but most of them focused on sudden safety-critical events or situations that were not predictable. Drivers' behaviors in these situations depended mostly on stimulus-reaction responses and involved no advanced driving skills, in particular, the anticipation of traffic development. Drivers' capability in anticipating and responding to latent hazards in a timely manner has been considered as a competence that accumulates with driving experience in non-automated vehicles (Stahl et al., 2014, 2016, 2019). In automated vehicles, although drivers no longer need to control the vehicle continuously most of the time, anticipatory driving is still expected to bring benefits to driving safety as it can allow drivers more time to prepare or respond to potential safety-critical events.

This dissertation extended the understanding of anticipatory driving not just in automated vehicles but also in non-automated vehicles. The role of experience in anticipatory driving was re-discovered for non-automated vehicles, and was uncovered for automated vehicles. The finding that experience enhances anticipatory behaviors can guide the training of drivers of automated vehicles. So far, a variety of training programs aimed to improve drivers' hazard perception skills have been adopted for non-automated vehicle drivers (e.g., Mills et al., 1996). However, there is no guidance on whether and how to train the drivers of automated vehicles. This dissertation provided insights into "how" to train drivers regarding anticipation skills; a clear association between visual attention and anticipatory driving was observed in non-automated vehicles, and drivers' reliance on automation was suggested to be an additional factor that can impede anticipatory driving in automated vehicles. Thus, such a training program may need to improve drivers' capability in identifying the area of interests on the road, allocating their attention more efficiently, and also developing a proper understanding of and reliance on automated driving systems. In other words, the findings from this dissertation may inspire what should be trained for future automated vehicle drivers, for example, by training them to guide their glances to areas of importance on road, similar to what has been done in hazard perception training for non-automated vehicle drivers, as well as by training them to better calibrate their reliance on, trust toward and understanding of the automation.

As a novel finding, it was found that distractions, particularly visual manual distractions, impeded anticipation in driving in both automated and non-automated vehicles. Distracted driving is strongly discouraged, and in some places is illegal for non-automated vehicles. However, it is a grey area for automated vehicles. The results of this research suggest that distracted driving needs to be avoided also in automated vehicles, at least from the anticipatory driving point of view and in situations where effective driver support systems are not present (e.g., in-vehicle displays to support anticipatory driving and inform drivers' of their states or traffic conditions). Thus, this research can inform policy makers to regulate automated vehicle driving behaviors.

Lastly, this research implies that when designing in-vehicle displays for automated vehicles, evaluation should go beyond just takeover performance. Previous display designs that were found to be effective in improving driving safety in abrupt-onset safety-critical events in automated vehicles may negatively impact drivers' capability in performing more advanced driving skills (i.e., the anticipatory driving skill). Drivers may allocate more responsibility to automation when they feel that such systems are reliable and capable enough to handle most of the situations that may arise while driving. This research provided one example display design that can calibrate drivers' reliance on automation and emphasized the importance of informing drivers of "context" information in automated vehicles. However, further research should explore whether this type of information is effective in scenarios different from those explored in this dissertation, as well as in supporting other driving skills apart from anticipation. The findings of this dissertation can also provide insights for future automated vehicle testing, i.e., the human-machine interface (HMI) design or automated driving system design should be tested in diverse situations and should take drivers' adaptation to the systems (e.g., change of attitude toward the systems) into consideration.

6.3 Limitations and future work

Although this dissertation has provided unique insights into anticipatory driving in both non-automated and automated vehicles, it has limitations. This section will discuss the limitations and future directions of this research.

The scenarios used in this dissertation were adopted and modified from earlier anticipatory driving studies (Stahl et al., 2014, 2016), which facilitated comparisons between the findings of this dissertation and the findings of these earlier studies. However, these scenarios represent only a few selected situations. Considering the complexity and diversity of traffic situations on the road, future research needs to consider incorporating more types of anticipatory driving scenarios. For example, slowing down or preparing to slow down was always considered as a valid anticipatory driving behavior in all scenarios in all three experiments in this dissertation. However, there are scenarios in which slowing down can be less suitable while accelerating can be a more appropriate way of avoiding conflicts. For example, emergency braking can lead to rear-end collision if the following vehicle is too close to the ego-vehicle when they are both approaching an intersection seconds before a traffic light turns red. Future research may need to consider scenarios like this to explore the generality of the findings in this dissertation. Further, the difficulty of the traffic conflicts (i.e., events) being anticipated was not controlled and their influence on the performance of anticipatory driving was not investigated in this dissertation. Future research could provide further insights on the factors influencing anticipatory driving by controlling the difficulty of the scenarios (e.g., by manipulating the visibility in the scenario, the number of cues being visible to the drivers before the traffic conflicts, or the time span between first cue onset to the event onset).

Second, although pre-event preparation was considered as a valid anticipatory driving behavior in automated vehicles, the methods used in this dissertation to identify anticipatory driving behaviors may still have excluded the anticipatory but reactive drivers, who anticipate but do not act or prepare to act proactively, in both non-automated and automated vehicles. These drivers, though they may choose not to take observable actions, still qualify as anticipatory drivers based on the definition of anticipatory driving. They should not be considered worse at anticipation compared to those who exhibit observable anticipatory driving behaviors. It also should be noted that the raters' driving experience was not controlled in the experiments and the raters were looking for anticipatory driving behaviors specifically. These may have introduced biases to their judgement. Future research may consider using more objective criteria for judging anticipatory driving.

Third, many factors may affect drivers' decision to take action or not, provided that they have appropriately anticipated the potential traffic conflicts, for example, their personality, their understanding of the automation capabilities, their reliance on the automation, and their perception and tolerance of risk. Unfortunately, although the demographic information of the participants (see Appendix Q, Appendix D and Appendix E), their attitude toward the automation (see Appendix R), their tendency to distraction (see Appendix P), and their driving style information (see Appendix O) were collected, due to small sample sizes in this research, the analysis of the influences of these factors on drivers' anticipatory driving behaviors is not feasible. Future research with different methodologies and a larger number of participants can investigate and potentially categorize drivers exhibiting different types of anticipatory driving behaviors in both non-automated and automated vehicles, and explore the underlying factors that lead to different types of anticipatory driving behaviors. Further, although the gender of the drivers was balanced in all three experiments, the analyses did not consider gender as an independent variable, as adding an additional independent variable would have reduced the power of the statistical tests and because the gender effect was not the focus of this research. Future research could potentially conduct additional analyses to assess the effects of gender on anticipatory driving.

Fourth, this dissertation considered the influence of only visual-manual distractions. However, other modalities of distraction can also affect drivers' performance in anticipatory driving, especially cognitive distraction. Cognitive distraction can interfere with both the perception and the analysis required to anticipate. Further research is needed to explore and compare the influences of different types of distractions on anticipatory driving, and may consider using real and common in-vehicle tasks (e.g., setting navigation). Further, although the monetary incentive was successful in encouraging participants to engage in the secondary task, future research may also consider building intrinsic motivation in the task design rather than depending on extrinsic motivation.

Fifth, it should be noted that only the non-automated driving experience was considered in this dissertation. It is reasonable to assume that at least in the next few years, there will still be very few drivers who are experienced in using automated driving systems, but a large number of drivers who are experienced in driving traditional non-automated vehicles. However, this assumption will not hold indefinitely. Provided that experience with automated systems and experience with non-automated systems can influence users' behaviors differently (e.g., reliance, Sanchez et al., 2014; Yuviler-Gavish & Gopher, 2011), it will also be necessary to consider how experience with automated driving systems will affect anticipatory driving in automated vehicles. Further, in Experiment 2 and Experiment 3, participants' experience with the automated driving systems was not controlled due to the difficulty in recruiting enough eligible participants. Although only a few participants had experience with the automated driving systems in Experiment 2 and Experiment 3, it may still have skewed the results in this dissertation. Future research should adopt stricter rules in screening participants.

Sixth, although an extra training drive was provided before the experimental drives in each experiment, it is possible that the novice and experienced drivers did not learn at the same rate and that more training was necessary.

Further, takeover quality or performance was not assessed in the experiments, but for Experiment 3. The only metric for takeover performance included in Experiment 3 was minimum gap time after event onset in action-necessary scenarios, where it served as a driving safety measure to compare the effectiveness of TORAC (TOR and automation capability information) and STTORAC (with TOR, automation capability information, and surrounding traffic information). Future research should incorporate more takeover performance and quality measures into study design.

Lastly, a limitation of the dissertation is that drivers' behaviors might have deviated from their real driving behaviors as the driving simulator may have provided an inaccurate sense of speed. The simulator imposed no real risk to drivers, except potential loss in experiment compensation, which was negligible compared to the risk in the real world if an actual crash were to occur. This may have potentially influenced drivers' behaviors and their choice of actions. Also, a fixed-base driving simulator was used, which provided no motion cues to the drivers. Since drivers were not visually monitoring the road continuously especially when they were allowed to engage in non-driving tasks, motion cues may play an essential role in informing drivers of the states (e.g., motion) of the automation, as suggested by Morando, Victor and Dozza (2016).

Lastly, as simulator experiments were used in this dissertation, drivers had a very short period of time experiencing the automated driving systems and the displays investigated. Previous research has suggested that drivers' performance in detecting hazards in automated vehicles would deteriorate with the progress of the experiment (Greenlee, DeLucia, & Newton, 2018). The low exposure to the automation in the experiments, combined with the highly reliable systems in the experiment, could have potentially made drivers behave differently compared to what they would do in real driving environments. Thus, an instrumented vehicle study or at least a study in a motion-based driving simulator is recommended to replicate and validate the findings of this dissertation.

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Appendices

Appendix A: Hazard Scenarios, Participant Profile, Experimental Environment and Non-Driving Tasks used in Hazard Perception Research for Non-automated Vehicles

Note:
- *Sudden onset hazard*: the situation does not allow for anticipation of the hazard
- *Environmental prediction hazard*: the two stimuli, hazard and precursor to the hazard are indirectly related, but there is a possibility that they occur together
- *Behavior prediction hazard*: future behavior of a traffic agent might be anticipated from the current behavior of that traffic agent
- *Anticipatory driving scenario*: the action of a traffic agent is dependent on and may be anticipated based on the actions of other traffic agents

	Hazardous scenario(s)	**Participant profile**	**Experimental environment & non-driving task**
Crundall et al. (2012)	- **Behavioral prediction hazards:** e.g., child being visible at roadside between parked cars stepped into road afterwards - **Environmental prediction hazards:** e.g., child stepped out from behind van into ego-lane	**Leaner group** - Mean age: 20.3 years old - Mean years of licensure: 7.5 months **Experience group** - Mean age: 33.0 years old - Mean years of licensure: 16.4 years **Driving instructor group** - Mean age: 48.5 years old - Mean years of licensure: 30 years - Mean instructing years: 13 years	- Driving simulator - No non-driving task
Lee et al. (2008)	- **Environmental prediction hazards**: hidden hazards might emerge from behind other road agents in the scenario	**Teenagers** - Mean age: 16.5 years old **Adults** (teenagers' parents) - Mean age: 47.2 years old	- Instrumented vehicle - **Visual-manual** text messaging task
Pradhan et al. (2005); Pradhan et al. (2003)	16 different scenarios in total with a mixed of three kinds of hazards: - **Anticipatory scenarios**: e.g., right-turn lead truck stopped at intersection because of crossing pedestrian - **Environmental prediction hazards**: e.g., when making a left turn, potential coming traffic on the opposite lane was visually obstructed by the leading truck - **Behavioral prediction hazards**: e.g., a vehicle with right signal might turn right into ego-path at an intersection	**Novice drivers** - Age: 16 or 17 years old - Less than 6 months of experience **Younger drivers** - Age: 19 – 29 years old **Older drivers** - Age: 60 - 75	- Driving simulator - No non-driving task
Mühl et al. (2019)	- **Anticipatory scenarios**: another car on the adjacent lane had to merge in front of ego-vehicle because of an obstacle on the lane, with traffic sign (*context cue, which does not provide information about others' intentions but can attract and focus attention to a specific event*) or turning signal (*target cue, elements triggering the intention of another's future behavior*) visible before merging	**Experienced drivers** - Mean age: 25.4 years old - Mean years of licensure: 7.9 years - Mean mileage per year: 56090 km **Novice drivers** - Mean age: 21.9 years old - Mean years of licensure: 4.2 years - Mean mileage per year: 4588 km	- Video simulation - Two levels of **auditory - verbal cognitive** load: low (repeat a specific letter out of 4 letters read to them) and high (2-back task)

Horberry et al. (2006)	- **Behavioral prediction hazards**: a pedestrian standing on the roadway near the edge - **Behavioral prediction hazards**: a car reversing down a driveway toward the road - **Abrupt-onset hazards**: a pedestrian crossing the road	**Younger drivers** - Mean age: 21 (< 25) years old **Mid-age drivers** - Mean age: 37 (30 - 45) years old **Older drivers** - Mean age: 66 (60 - 75) years old	- Driving simulator - **Auditory vocal** task (hands-free cellphone conversation) - **visual manual** task (interacting with in-vehicle infotainment system, self-paced)
Borowsky, Shinar and Oron-Gilad (2010)	12 scenarios with a mixed of two types of hazards: - **Behavioral prediction hazards**: e.g., vehicles approaching main road from a driveway, visually blocked by a bus at the intersection when stopped - **Environmental prediction hazards**: e.g., a pedestrian about to approach the crosswalk on the curb was blocked by a parked car. A warning sign ahead notified the existence of the crosswalk.	**Experienced drivers** - Mean age: 41.0 (31 - 49) years old - Mean years of licensure: 24.3 years	- Driving simulator - Interruption task where the front display was replaced with a **visual spatial** memory task lasted for 2 seconds following the visual cue that gave information about the hazards and the task disappeared before the hazard was visible
Pradhan et al. (2011)	- Four different kinds of **environmental prediction hazards**: e.g., stop sign at the intersection blocked by a parked van; a pedestrian appeared in front of a van parked on the shoulder of a road	**Newly licensed drivers** - Mean age: 16.5 years old **Experienced adult drivers** (parent of newly licensed drivers) - Mean age: 47.2 years old	- Instrumented vehicle - Odometer task (**visually** monitor the odometer and **orally** report whenever the last digit showed a 3, 6 or 9) - **Visual manual** task: send test message - Dial 511 using hand-held phone, listen and orally report incidents
Savage et al. (2013)	A variety kind of hazards from DVLA test: - **Behavioral prediction hazard**: e.g., vehicle approached the main road from a driveway being visible faraway - **Environmental prediction hazard**: e.g., pedestrian walked out from vehicles parked besides road - **Abrupt-onset hazard**: vehicles suddenly appeared from a hidden driveway	- Age 18 to 34 years old - Have DVLA approved driver's license - Drove at least one year	- Video simulation - Cognitive task imposed by audio puzzle (no versus high)
Huestegge et al. (2010)	Used static pictures of hazardous or potential hazardous scenarios. Based on the examples, it may involve: - **Environmental prediction hazards**: e.g., pedestrian might walk from between parked cars - **Abrupt-onset hazards**: e.g., child sudden run into ego-lane	**Inexperienced drivers** - Mean age: 18 years old - Mean years of licensure: 9 (0 - 23) months - Mean lifetime mileage: 6536 km **Experienced drivers** - Mean age: 24 years old - Mean years of licensure: 5 (2 - 8) years - Mean lifetime mileage: 22942 km	- Video simulation - No non-driving task
Pradhan et al. (2009)	**Environmental prediction hazards**: e.g., pedestrian crosswalk at an intersection with sidewalk hidden behind high hedge	- Age 18 to 21 years old - Hold valid US driver's licence for at least 1 year - Normal vision or vision corrected to normal with contact lenses	- Instrumented vehicle - No non-driving task
Castro et al. (2019)	24 video clips consisted of a variety of types of hazards: - **Abrupt-onset hazard**: e.g., a car suddenly joined the lane	**Novice drivers** - Mean age: 21.71 (SD = 2.99) years old - Mean years of licensure: 4.49 years (SD = 3.18) **Experienced drivers**	- Video simulation - No non-driving task

	- **Behavioral prediction hazard**: e.g., a pedestrian was about to cross from behind vegetation - **Environmental prediction hazards**: e.g., hidden by the vehicle in front of us, a group of pedestrians crossed at the crossroads	- Mean age: 39.51 (SD = 10.43) years old - Mean driving experience: 20.07 years (SD = 10.48)	
Upahita, Wong and Lum (2018)	- **Behavioral prediction hazard**: A pedestrian crossed at a zebra crossing or jaywalked but both are visible in advance; A heavy truck entered the ego-lane from a ramp, being visible ahead; - **Abrupt-onset hazard**: a car come from the minor road (without right of way) on the left and then made a right turn crossing the path trajectory of the ego-vehicle	**Active drivers** - Held a driving license for more than 2 years and has been driving regularly **Novice drivers** - Held a driving licence but has not been driving since obtaining licence within the last three months **Inactive drivers** - Held a driving licence but has not been driving since obtaining licence more than three months ago **No license participants** - No valid driving licence	- Driving simulator study - No non-driving task
Ebadi et al. (2019)	- **Environmental prediction hazards**: e.g., a pedestrian crossing obscured by vegetation in an intersection - **Abrupt-onset hazard**: e.g., a parked vehicle suddenly merging into the ego-lane	- Mean age: 24.79 (SD = 2.97) years old - Mean years of licensure: 6.07 years (SD = 2.67)	- Driving simulator study - **Auditory-verbal** hands-free mock cell phone task
Borowsky et al. (2015)	- 2 **behavioral prediction hazards**: A car from the left was going to turn left into the ego-lane (straight lane) in a T-intersection; A parked vehicle on the right might merge into the ego-lane with left signals on	**Participants with non-driving task** - Mean age: 39.7 (31-48) years old - Mean years of licensure: 22.8 years **Participants W/O non-driving task** - Mean age: 42.2 (33-49) years old - Mean years of licensure: 25.7 years	- Driving simulator study - **Visually** fixating on an asterisk among 11 other moving ones, when the front view was replaced by the task display
Jackson et al. (2009)	25 short clips with a mixture of genuinely occurring hazards (14 clips) and staged clips, which were similar to naturally occurring hazards. The clips were between 4 and 24 s long and were stopped immediately prior to the hazardous situation starting yet with enough information for the viewer to predict or at least make an educated guess as to what might happen next. No detailed descriptions of the scenarios were provided.	**Novice drivers** - Mean age: 21.71 (SD = 2.99) years old - Mean years of licensure: 4.49 years (SD = 3.18) **Experienced drivers** - Mean age: 39.51 (SD = 10.43) - Mean years of licensure: 20.07 years (SD = 10.48)	- Video-based test - no non-driving task

Appendix B: A summarization of Takeover Scenarios and Supporting Information/TOR in Automated Driving Studies

	Takeover scenario	**Automation & Experimental environment**	**Non-driving task**	**TOR and/or supporting information**
Gold et al. (2015)	- A stranded truck on the ego-lane	- **Lateral** and **longitudinal** automation - Driving simulator	2 levels: - no task - 20-Questions-Task (Modality not mentioned)	**Audio** TOR 7 seconds before collision
Gold, Damböck, Bengler, et al. (2013)	- A person being visible 6 sec ahead, stepping toward the ego-lane when the ego-vehicle was 4 seconds away - A compressor being visible 6 sec ahead, started rolling into the ego-lane when the ego-vehicle was 4 sec away; - 4 other uncritical situations	- **Lateral** and **longitudinal** automation - Driving simulator	None	**Visual** and **auditory** monitor request (MR) when the ego-vehicle was 6 seconds away
Zeeb et al. (2015)	- Ego-lane being blocked by construction/broken vehicle being visible after leading vehicle moves away, with 1.5 sec time budget - Similar situations but drivers were given 12 sec time budgets before reaching the obstacle.	- **Lateral** and **longitudinal** automation - Driving simulator	**2 visual-manual** tasks: - Simple text entries (e.g., completing the missing word of a sentence or copying a given sentence) - Internet searches (e.g., going to a mobile site or using a search engine)	Visual and auditory TOR 2.5, 3.0 or 3.5s before reaching the obstacle
Zeeb, Buchner and Schrauf (2016)	- Faded lane marks in non-critical situation - Faded lane marks on curve with gust, being critical and with 4 sec time budgets - Additional lane (required to merge to the rightmost lane by law, non-critical) - Blocking of the ego-lane by construction	- **Lateral** and **longitudinal** automation - Driving simulator	**3 visual-manual** tasks in the multimedia system: - Email (read and reply an invitation) -Reading news (select and read a business article) - Watching video task (select and watch scientific TV shows)	**Visual** and **auditory** TOR - 4 s before the system was deactivate in the situation of faded lane in curve situation. - 200 m ahead in construction situation
Walch et al. (2015)	- In fog, a broken vehicle was recognizable 190m ahead; - In fog, a sharp curve appeared 30m ahead	- **Lateral** and **longitudinal** automation - Driving simulator	**Visual-audio** task - Watch a video and answer questions afterwards.	3 types of **Visual** and **auditory** TOR: - A “caution fog” alert followed by a TOR 6 seconds before entering fog - TOR 4 seconds before entering fog - TOR 6 seconds before entering fog
Körber et al. (2015)	5 situations that drivers needed to take over, e.g. a broken car obstructed ego-lane being visible until TTC of 10 sec	- **Lateral** and **longitudinal** automation - Driving simulator	**Visual-manual task:** - Surrogate Reference Task (SuRT)	- **Audio** TOR at TTC of 3 sec
Mok et al. (2015)	- Lane marks were missing because of construction site surrounded by traffic pylons	- **Lateral** and **longitudinal** automation - Driving simulator	**Visual task**: - Watch a video on iPad	**Visual** and **auditory** TOR 2, 5, 8 sec before transfer of control to the driver

Feldhütter et al. (2017)	- A stationary vehicle on the ego-lane visible 6 sec in advance	- **Lateral** and **longitudinal** automation - Driving simulator	2 levels: - No task **- Visual** SuRT	**Audio** TOR at TTC of 6 sec when stationary vehicle became visible
Louw et al. (2015)	Events happened in light or heavy fog: - Non-critical events: the lead vehicle sped up - Critical events: the lead vehicle braked at TTC of 5 sec	- **Lateral** and **longitudinal** automation - Driving simulator	None	- **Visual auditory** Forward Collision Warning at TTC of 2 sec; - **Audio** beep and **visual** cues for changes of automation states (unavailable, available, engaged, uncertain, disengaged)
Radlmayr et al. (2014)	- Sudden end of lane due to obstacles, e.g., a car crashes with two stationary cars with flash warnings on, visible 7 sec in advance	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual** SuRT **- Audio-verbal** 2-back Task - Tactile detection response task (DRT): tactile signals presented on participants' neck via a vibrating node and participants respond by pushing a button	**Visual auditory** TOR when the automation reaches limits (TTC not specified)
Lorenz et al. (2014)	- Ego-lane and right lane blocked by accidents with warning lights on (visibility distance not mentioned)	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual** SuRT	- **Visual auditory** TOR 7 sec before crash. - AR display showing corridor on the road to be avoided or corridor the driver can safely steer through
Gold, Damböck, Lorenz, et al. (2013)	- Ego-lane blocked by accident, revealed after the leading vehicle drove away at TTC of 5 or 7 sec	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual** SuRT	- **Visual auditory** TOR when the accident was revealed, either 5 or 7 sec in advance
Kerschbaum, Lorenz and Bengler (2015)	- The ego-lane was blocked by an accident, being visible 7 sec in advance	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual** SuRT	- **Visual auditory** TOR
van den Beukel and van der Voort (2013)	- The lead vehicle braked at -8m/s^2, with three criticality levels based on three time-headway	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual-manual** secondary task: moving a blue dot to avoid collision with red dots	- **Auditory** warning when lead vehicle braked
Melcher et al. (2015)	- End of road with construction site that required a lane change; drivers allowed 10 seconds time budgets after TOR	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual-manual** quiz game on cellphone	**Visual auditory** TOR and/or brake **jerk** - Mobile phone integrated + no brake jerk - Mobile phone integrated + brake jerk - Mobile phone not integrated + no brake jerk - Mobile phone not integrated + brake jerk
Körber et al. (2016)	- A broken vehicle on ego-lane visible 233 m ahead.	- **Lateral** and **longitudinal** automation - Driving simulator	- **Audio verbal** task: 20-Questions Task, i.e., asking 20 questions to guess an animal	- **Audio** TOR 7 sec before collision

Merat et al. (2014)	- The motorway reduced to one lane because of incidents or road works, as notified by message signs 300 metres in advance - The automation was disengaged for no reason on fixed or variable intervals	- **Lateral** and **longitudinal** automation - Driving simulator	None	None
Naujoks et al. (2017)	- Ego-vehicle was unable to follow the lane because of missing lane marks, temporary lane marks and road section with high curvature	- **Lateral** and **longitudinal** automation - Driving simulator	2 Levels: - No task - A **visual manual** task (retrieving weather information) on a screen attached to the right top corner of the infotainment system display	- **Visual auditory** TOR 20 m after entered the problematic area
Naujoks et al. (2015)	- Non-critical scenarios - Critical situations that required driver takeover, including vehicle cut in, lead vehicle suddenly moves out of ego-lane revealing a standstill vehicle, and lead vehicle brake	- **Lateral** and **longitudinal** automation - Driving simulator	None	- Two levels of **visual auditory** TOR ("soft" for transitions likely to happen in the near future; "hard" for an immediate takeover) - A **visual** display showing system states (activated or not, lane detected or not), lead vehicle and traffic jam, and road type
Naujoks and Neukum (2014)	- Pedestrians entered ego-lane from between parked cars - Turning vehicle/crossing cyclist takes right of way	- Advanced driver assistance systems (ADAS, function not specified) - Driving simulator	None	**Visual (**on a HUD**) auditory** TOR - Conflict-specific - Conflict-unspecific Provided **when** - At time-of-no-return (assuming deceleration of $8/m^2$ for 1 sec) - At 2 sec before time-of-no-return
Nilsson (1995)	- Sudden brake of lead vehicle ($8m/s^2$) - Sudden cut in of front vehicle - Stationary queue not recognized by ACC	- **Longitudinal** automation - Driving simulator	None	- **Audio** TOR at the moment of event (except for stationary queue)
MarkVollrath, Schleicher and Gelau (2011)	- Fogbank requiring a change of speed to pass - Sharp curve requiring a change of speed to pass	- **Longitudinal** automation (ACC and CC) - Driving simulator	- **Visual-manual** SuRT task, only in part of drive without critical events	None
de Waard et al. (1999)	- The system failed and got very close to a lead vehicle (0.1 m distance)	- Automated Highway System, being able to form a platoon of cars - Driving simulator	None	None
Shen and Neyens (2017)	- Drifts due to wind gust, accompanied with unannounced lane keeping failure	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual-verbal** task: watching a movie and answering 2 multiple-choice questions about the content	None

Eriksson and Stanton (2017b)	**Non-safety-related** transfer of control (as requested), either from automation to manual driving or from manual driving to automation	- Highly automated driving system (not mentioned, but likely with lateral and longitudinal automation) - Driving simulator	- **Visual** task: reading an issue of *National Geographic*	- Computer-generated female voice stating, "Please resume control" or "Automation avail-able."
Seppelt and Lee (2007)	- The brake of the lead vehicle that exceeded the automation capability - Fog and rain that attenuated the sensor sensitivity	- **Longitudinal** automation - Driving simulator	- **Audio-verbal** task: requiring drivers to listen to messages and answer questions about restaurants	- Continuous **visual** EID about the relationship between the ego-vehicle and the lead vehicle, as well as sensor degradation
Gaspar and Shull (2019)	- Automation failed to detect lane marks and began to drift out of its lane	- **Lateral** and **longitudinal** automation - Driving simulator	- **Visual-manual task:** answering questions on a tablet located on a stand to their right	**- Discrete**: audio-visual TOR when the automation limit was exceeded **- Continuous visual** information on automation confidence - **Continuous visual and auditory**: audio chime when the confidence drops
Damböck et al. (2012)	- The system fails to detect the change of speed limit and slow down automatically - The system failed to detect the ego-lane and changed to neighbouring lane - The system failed to detect the lead vehicle and accelerated toward it	- **Lateral** and **longitudinal** automation - Driving simulator	None	- AR display showing the "trajectory", the detected lead vehicle and the speed limit
Politis et al. (2014)	- Sudden brake of lead vehicle	- **Lateral** and **longitudinal** automation - Driving simulator	None	- Warning of 3 levels of criticality (level high, level medium and level low), with 7 combination of 3 modalities (audio, visual, and tactile)
Greenlee et al. (2018)	- In heavy fog (visibility of 175 ft), there are stopped vehicles in or near an intersection	- **Lateral** and **longitudinal** automation - Driving simulator	None	None

Appendix C: Poster for Experiment 1, 2 & 3

Participants Needed!

For a high-fidelity driving simulator study on driving behavior

If you are able to drive without glasses (contact lenses are allowed), can read and speak English,

- **Have a G driver' s license or equivalent for MORE than 8 years**

OR

- **Have at least G2 license or equivalent for LESS than 3 years**

Location: Rosebrugh Building (RS) 164 College St.
Toronto, ON M5S 3G8
Duration: approximately 3 hours
Compensation: $14/hr + up to $8 bonus

To get started, fill out this short screening questionnaire:
https://goo.gl/KyQvTZ
For more information, contact Dengbo He at hedengbo@mie.utoronto.ca

Mechanical & Industrial Engineering
UNIVERSITY OF TORONTO

Human Factors
& Applied Statistics Lab

Appendix D: Screening Questionnaire for Experiment 1

University of Toronto
Human Factors and Applied Statistics Lab
Driving Experiment Eligibility Questionnaire

You are invited to participate in a driving simulator research conducted by the Human Factors and Applied Statistics Lab (Director: Prof. Birsen Donmez) at the University of Toronto.

The goal of this research is to make our roads safer by understanding driver behaviors under specific situations. The following questionnaire will help us assess your eligibility for the study. If you are eligible, you will be invited to our laboratory.

Please note that all information collected will be held in the strictest confidentiality. Personal data will be stored securely in the Human Factors and Applied Statistics Lab's **secure password-protected Network Attached Storage** at the University of Toronto. Under no circumstances will personal data be revealed to any third party, for any purpose. **If you are not chosen for this experiment and do not want to be informed for future driving study in our lab, your information will be deleted.**

Please note that personal contact information will be used solely for the purpose of future research opportunities at our lab, if you so desire.

If you have any questions or concerns you would like to be addressed before or after completing this questionnaire, please contact the investigator at hedengbo@mie.utoronto.ca (647-995-4236).

- What is your first name? ________________________
- What is your last name?________________________
- Your email address (if there is one): ________________________
- Your phone number: ________________________
- Your preference on the method of contact:

  email / phone / both

- If you are interested in participating in future research at the Human Factors and Applied Statistics Lab, please indicate below (if you are not interested, you can skip this question).

  I am interested in participating in your future research; please contact me when opportunities become available.

Simulator Sickness Screening

Some people tend to experience a type of motion sickness, called simulator sickness, when driving the simulator. The next questions are asked to help us identify if you might be prone to simulator sickness.

- Have you ever driven in a driving simulator?
    - No, never
    - Once or twice
    - Multiple times
    - Regularly
- If you have used a driving simulator before, did you experience simulator sickness?
    - Yes
    - No
- Do you frequently experience migraine headaches?
    - Yes
    - No
- Do you experience motion sickness?
    - Yes
    - No
- Do you experience claustrophobia?
    - Yes
    - No
- Are you pregnant?
    - Yes
    - No

Driver Survey

Please fill in the blanks or circle the one best response unless otherwise noted.

- What is your age? ____________________
- What is your sex?
    - Male
    - Female
    - Other
    - Prefer not to answer
- Do you ordinarily wear corrective lenses (e.g., glasses) of any kind?
    - Yes
    - No
- If you do have corrected vision, are you able to wear contact lenses during the experiment?
    - Yes

    - No
- Are you right-handed?
    - Yes
    - No
- What are your current driver's licenses (you may select multiple responses)?
    - Full license (e.g. G license in Ontario)
    - Learner’s license (e.g. G1 and G2 licenses in Ontario)
    - Motorcycle (M, M1 and M2 in Ontario)
    - I don’t have a driver’s license
    - Other licenses (please specify)
- When did you obtain your first driver’s license (knowledge test, i.e., G1 in ON, Canada or equivalent)? (MM / YYYY)

  ____

- When did you obtain your full driver’s license, if you have it? (MM / YYYY)

  ____

- What type of motor vehicle do you drive most often?
    - Passenger car
    - Pick-up truck
    - Cargo van
    - Box/Delivery truck
    - Motor cycle
    - Bus, tractor trailer, vehicle with more than 2 axles
    - Other, please specify
    - I don’t know
- What are your primary reasons for driving in a typical week (you can select multiple responses)?
    - Commuting
    - Business
    - Shopping
    - Social
    - Recreational
    - Other, please specify
    - I prefer not to answer
- If you drive for commuting, please specify your one-way distance:
    - under 10km
    - 10km to 20km

    - 20km to 30km
    - Above 30km
    - I don’t know
- How often do you drive a car or other motor vehicle?
    - Almost every day
    - A few days a week
    - A few days a month
    - A few times a year or less
    - Never
- Out of the total distance you drove for the past 1 year, what percentage (out of 100%, in total) took place:

  In the downtown area:
  On the highway or freeway:
- Over the past 1 year, how many kilometers did you drive?
    - Under 10,000 km
    - Between 10,001 km and 20,000 km
    - Between 20,001 km and 50,000 km
    - Over 50,001km
    - None
    - I don't know
- On a scale of 1 to 10, with 1 being very unsafe and 10 being very safe, how safe a driver do you think you are?

1	2	3	4	5	6	7	8	9	10
Very Unsafe									Very Safe

- In the past three years, how many times have you been stopped by a police officer and received a **warning** (but no citation or ticket) for a moving violation (i.e. speeding, running a red light, running a stop sign, failing to yield, reckless driving, etc.)?

  Enter a number (enter 0 for none.): _________
- In the past three years, how many times have you been stopped by a police officer and received a **citation or ticket** for a moving violation?

  Enter a number (enter 0 for none.): ___________
- In the past three years, how many times have you been in a **vehicle crash** where you were the driver of one of the vehicles involved?

  Enter a number (enter 0 for none.): ___________

- How would you describe your **physical** well-being (in the past month)?
    - Excellent
    - Good
    - Average
    - Fair
    - Poor
- How would you describe your **mental** well-being (in the past month)?
    - Excellent
    - Good
    - Average
    - Fair
    - Poor
- Compared with others your age, how would you rate your overall **vision**? (If you wear glasses or contacts, rate your corrected vision when you are wearing them.)
    - Excellent
    - Good
    - Average
    - Fair
    - Poor
- Compared with others your age, how would you rate your overall **hearing**?
    - Excellent
    - Good
    - Average
    - Fair
    - Poor
- Compared with others your age, how would you rate your overall **memory**?
    - Excellent
    - Good
    - Average
    - Fair
    - Poor

Appendix E: Screening Questionnaire for Experiment 2 & 3

University of Toronto
Human Factors and Applied Statistics Lab
Driving Experiment Eligibility Questionnaire

You are invited to participate in a driving simulator research conducted by the Human Factors and Applied Statistics Lab (Director: Prof. Birsen Donmez) at the University of Toronto. This survey may take 10 minutes in total.

The goal of this research is to make our roads safer through understanding driving behaviors under specific situations. The following questionnaire will help us assess your eligibility for the study. If you are eligible, you will be invited to our laboratory.

Please note that all information collected will be held in the strictest confidentiality. Personal data will be stored securely in the Human Factors and Applied Statistics Lab's secure password-protected Network Attached Storage at the University of Toronto. Under no circumstances will personal data be revealed to any third party, for any purpose. If you are not chosen for this experiment and do not want to be informed for future driving study in our lab, your information will be deleted.

Please note that your personal contact information will only be used if you indicate that you want to take part in future lab studies.

If you have any questions or concerns you would like to be addressed before or after completing this questionnaire, please contact the investigator at drivingsimulatorstudy@gmail.com.

- What is your first name? ________________________
- What is your last name?________________________
- What is your age? ___________________
- What is your gender?
  - Male
  - Female
  - Other
  - Prefer not to answer
- Your email address (if there is one): ________________________

  Your phone number: ________________________
- Your preference on the method of contact:

email / phone / both

- If you are interested in participating in future research at the Human Factors and Applied Statistics Lab, please indicate below (if you are not interested, you can skip this question).

  I am interested in participating in your future research; please contact me when opportunities become available.

Simulator Sickness Screening

Some people tend to experience a type of motion sickness, called simulator sickness, when driving the simulator. The next questions can help us identify if you might be prone to simulator sickness.

- Have you ever driven in a driving simulator before?
  - No, never
  - Once or twice
  - Multiple times
  - Regularly
- (logic: only when “No, never” was not chosen in last question.) If you have used a driving simulator before, did you experience simulator sickness?
  - Yes
  - No
- Do you frequently experience migraine headaches?
  - Yes
  - No
- Do you experience motion sickness?
  - Yes
  - No
- Do you experience claustrophobia?
  - Yes
  - No
- Are you pregnant?
  - Yes
  - No

Driver Survey

Please fill in the blanks or choose the best one(s) unless otherwise noted.

- Do you ordinarily wear corrective lenses (e.g., glasses) of any kind?
    - Yes
    - No
- (Logic: only shows when "Yes" is chosen in last question) If you do have corrected vision, are you able to wear contact lenses during the experiment?
    - Yes
    - No
- Are you right-handed?
    - Yes
    - No
- What is your current driver's license?
    - G license in Ontario or full license in the U.S.
    - G2 license in Ontario or equivalent in the U.S.
    - G1 licenses in Ontario or equivalent in the U.S.
    - I don't have a driver's license
    - Other licenses (please specify)
- When did you pass your FIRST road test and obtain corresponding driver's license (e.g., G2 license in ON, Canada or equivalent)? (MM / YYYY)?

  ____

- When did you obtain your FIRST full driver's license, if you have it? (MM / YYYY)

  ____

- What type of motor vehicle do you drive most often?
    - Passenger car
    - Pick-up truck
    - Cargo van
    - Box/Delivery truck
    - Bus, tractor trailer, vehicle with more than 2 axles
    - Other, please specify
- What are your primary reasons for driving in a typical week (you can select multiple responses)?
    - a. Commuting
    - b. Business

- c. Shopping
- d. Social
- e. Recreational
- f. Other, please specify

- (Logic: only when “a” is chosen in last question) If you drive for commuting, please specify your one-way distance:
  - a. under 10km
  - b. 10km to 20km
  - c. 20km to 30km
  - d. Above 30km
- How often do you drive a car or other motor vehicle?
  - Almost every day
  - A few days a week
  - A few days a month
  - A few times a year or less
  - Never
- Over the past 1 year, how many kilometers did you drive?
  - Under 10,000 km
  - Between 10,001 km and 20,000 km
  - Between 20,001 km and 30,000 km
  - Between 30,001 km to 40,000 km
  - Between 40,001 km to 50,000 km
  - Over 50,001km
  - None
- On a scale of 1 to 10, with 1 being very unsafe and 10 being very safe, how safe a driver do you think you are?

1	2	3	4	5	6	7	8	9	10
Very Unsafe									Very Safe

- In the past three years, how many times have you been stopped by a police officer and received a **warning** (but no citation or ticket) for a moving violation (i.e. speeding, running a red light, running a stop sign, failing to yield, reckless driving, etc.)?

  Enter a number (enter 0 for none.): ___________

- In the past three years, how many times have you been stopped by a police officer and received a **citation or ticket** for a moving violation?

  Enter a number (enter 0 for none.): ___________

- In the past three years, how many times have you been in a **vehicle crash** where you were the driver of one of the vehicles involved?

  Enter a number (enter 0 for none.): ___________

Vehicle Automation Screening Questionnaire

<u>Question A:</u>
Please read through the description of the Cruise Control (CC) system carefully before you proceed to the questions.

* **Cruise Control**:
<u>What it does</u>: the system maintains a constant vehicle speed that is set by the driver.
<u>How it works</u>: The system automatically controls the acceleration to increase or decrease the gas inputted into the engine to maintain the driver's set speed.
<u>Limitation(s)</u>: The system does not slow down the car when there is a need (e.g., traffic ahead).

- 1. Before reading the description above, how much did you know about cruise control?
  - I never heard about it
  - I heard about it but did NOT know what it does
  - I knew what it does, but did NOT know how it worked
  - I knew what it does and how it works, but did NOT know its limitations
  - I knew what it does, how it works, and its limitations
- 2. Have you ever used this system?
  - Yes
  - No
- (logic: if answer is "yes" in question 2.) 3. How often have you used it?
  - Less than once a year
  - Several times a year
  - Several times a month
  - Several times a week
  - Almost every day
- 4. Do you own or frequently drive a car equipped with this system?
  - Yes
  - No
- 5. (logic: if "Yes" in question 4 and "Yes" in question 2) Have you ever used this system equipped on your car or the car you frequently drive?
  - Yes
  - No

- 6. (logic: “No” is given in question 5 and “Yes” is given in question 4.) Why haven’t you used this system in your own car or the car you often drive? (Check all that apply)
    - I don’t know how to use it
    - It is too complicated to use (too many steps to activate or deactivate it)
    - The instructions make no sense
    - I don’t trust it
    - I tried it a few times and I felt unsafe
    - Other: _____
- 7. (Logic: if “Yes” in question 2) Have you ever been involved in any accidents while using this system?
    - Never
    - Once
    - 2-3 times
    - More than 3 times

Question B:
Please read through the description of the Adaptive Cruise Control (ACC) system carefully before you proceed to the questions.

* **Adaptive Cruise Control**:
What it does: the system functions like cruise control, however, it is more advanced as it also automatically adjusts the vehicle speed to maintain a safe distance from a leading vehicle.
How it works: the system uses radar equipped in front of the vehicle to detect the distance to a leading vehicle. It controls the acceleration similar to cruise control to maintain a set speed, but also decelerates if the leading vehicle slows down.
Limitation(s): the automation is imperfect, and may not work properly in poor weather conditions and does not detect stationary objects (e.g., a stopped vehicle). Additionally, depending on the specific system, the system may not apply the full braking force to bring the vehicle to a complete stop or slow the vehicle down enough to maintain a safe distance to the vehicle ahead.

- 1. Before reading the description above, how much did you know about Adaptive Cruise Control?
    - I never heard about it
    - I heard about it but did NOT know what it does
    - I knew what it does, but did NOT know how it worked
    - I knew what it does and how it works, but did NOT know its limitations
    - I knew what it does, how it works, and its limitations
- 2. Have you ever used this system?
    - Yes
    - No

- (logic: if answer is "yes" in question 2.) 3. How often have you used it?
    - Less than once a year
    - Several times a year
    - Several times a month
    - Several times a week
    - Almost every day
- 4. Do you own or frequently drive a car equipped with this system?
    - Yes
    - No
- 5. (logic: if "Yes" in question 4 and "Yes" in question 2) Have you ever used this system equipped on your car or the car you frequently drive?
    - Yes
    - No
- 6. (logic: "No" is given in question 5 and "Yes" is given in question 4.) Why haven't you used this system in your own car or the car you often drive? (Check all that apply)
    - I don't know how to use it
    - It is too complicated to use (too many steps to activate or deactivate it)
    - The instructions make no sense
    - I don't trust it
    - I tried it a few times and I felt unsafe
    - Other: _____
- 7. (Logic: if "Yes" in question 2) Have you ever been involved in any accidents while using this system?
    - Never
    - Once
    - 2-3 times
    - More than 3 times

<u>Question C:</u>
Please read through the description of the Lane Departure Warning (LDW) system carefully before you proceed to the questions.

* **Lane Departure Warning**:
<u>What it does</u>: the system is designed to warn drivers when the vehicle begins to move out of its lane (unless a turn signal is on in that direction) on freeways and arterial roads.
<u>How it works</u>: this system uses a camera to recognize the lane markings on the road and the boundaries of the lanes.
<u>Limitation(s)</u>: this warning system is imperfect and may not work properly when the lane markings are not clearly visible, e.g., poor weather or road conditions. Additionally, this system is not always accurate, and may provide false alarms.

- 1. Before you reading the description above, how much did you know about Lane Departure Warning?
    - I never heard about it
    - I heard about it but did NOT know what it does
    - I knew what it does, but did NOT know how it worked
    - I knew what it does and how it works, but did NOT know its limitations
    - I knew what it does, how it works, and its limitations
- 2. Have you ever used this system?
    - Yes
    - No
- (logic: if answer is "yes" in question 2.) 3. How often have you used it?
    - Less than once a year
    - Several times a year
    - Several times a month
    - Several times a week
    - Almost every day
- 4. Do you own or frequently drive a car equipped with this system?
    - Yes
    - No
- 5. (logic: if "Yes" in question 4 and "Yes" in question 2) Have you ever used this system equipped on your car or the car you frequently drive?
    - Yes
    - No
- 6. (logic: "No" is given in question 5 and "Yes" is given in question 4.) Why haven't you used this system in your own car or the car you often drive? (Check all that apply)
    - I don't know how to use it
    - It is too complicated to use (too many steps to activate or deactivate it)
    - The instructions make no sense
    - I don't trust it
    - I tried it a few times and I felt unsafe
    - Other: _____
- 7. (Logic: if "Yes" in question 2) Have you ever been involved in any accidents while using this system?
    - Never
    - Once
    - 2-3 times
    - More than 3 times

Question D:

Please read through the description of the Lane Keeping Assist (LKA) system carefully before you proceed to the questions.

* **Lane Keeping Assist**:
What it does: the system is designed to steer the vehicle to keep it centered in the lane.
How it works: this system uses a camera to recognize the lane markings on the road and the boundaries of the lane, and based on that information, it continuously steers the car.
Limitation(s): the use of this system is limited to highway driving. It may not work properly when the lane markings are not clearly visible (e.g., poor weather or road conditions), or when driving around sharp curves.

- 1. Before reading the description above, how much did you know about Lane Keeping Assist?
    - I never heard about it
    - I heard about it but did NOT know what it does
    - I knew what it does, but did NOT know how it worked
    - I knew what it does and how it works, but did NOT know its limitations
    - I knew what it does, how it works, and its limitations
- 2. Have you ever used this system?
    - Yes
    - No
- (logic: if answer is "yes" in question 2.) 3. How often have you used it?
    - Less than once a year
    - Several times a year
    - Several times a month
    - Several times a week
    - Almost every day
- 4. Do you own or frequently drive a car equipped with this system?
    - Yes
    - No
- 5. (logic: if "Yes" in question 4 and "Yes" in question 2) Have you ever used this system equipped on your car or the car you frequently drive?
    - Yes
    - No
- 6. (logic: "No" is given in question 5 and "Yes" is given in question 4.) Why haven't you used this system in your own car or the car you often drive? (Check all that apply)
    - I don't know how to use it
    - It is too complicated to use (too many steps to activate or deactivate it)

    - The instructions make no sense
    - I don’t trust it
    - I tried it a few times and I felt unsafe
    - Other: _____
- 7. (Logic: if “Yes” in question 2) Have you ever been involved in any accidents while using this system?
    - Never
    - Once
    - 2-3 times
    - More than 3 times

Thank you for taking our survey. Your response is very important to us. We will contact if you are eligible for our experiment.

Appendix F: Consent Form for Drivers without Secondary Task

Participant Consent Form

Title: Simulator experiment on driving behavior

Investigators: **Prof. Birsen Donmez, PhD PEng | Associate Professor**

Department of Mechanical & Industrial Engineering
Faculty of Applied Science & Engineering | University of Toronto

Tel: 416-978-7399 Email: donmez@mie.utoronto.ca

Mr. Dengbo He, PhD Candidate

Department of Mechanical & Industrial Engineering
Faculty of Applied Science & Engineering | University of Toronto

Tel: 647-995-4236 Email: hedengbo@mie.utoronto.ca

You are being asked to take part in a **PhD** research study from **Human Factor and Applied Statistic Lab, University of Toronto**. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks and precautions associated with this study. In order to decide whether you wish to participate or withdraw in this research study, you should understand its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the investigator to explain any words you don't understand before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this document.

Purpose

This study aims to understand driver's behavior under specific conditions. As a participant you will be asked to:

- Fill out a series of questionnaires
- Wear measurement devices on your body
- Drive through a simulated environment

Procedure

There are 6 parts to this study:

1. Screening and Recruitment: You were asked to fill out a screening questionnaire to provide information on your driving history and habits. Based on this information, your eligibility was assessed, and you were invited to take part in this research study.

2. Orientation and Training: You will be provided with written and verbal information on the experiment and its procedures. You will then be trained using the driving simulator. This part will take about 25 min.

3. Equipment Calibration: An eye tracking system (measuring glance location), heart rate and skin conductance (or sweat) sensors, and video cameras are used in this experiment. These systems will be calibrated. The heart rate and skin conductance electrodes will be placed on your body. This part will take about 15 min.

4. Experimental Drives: You will complete 5 drives in the simulator, each about 10 minutes long. After each drive, you will be asked to complete a questionnaire, which takes about 5 minutes. You will be given a 5-minute break before the next drive. The experimental drives overall will take about 100 min.

5. Post-experiment Questionnaire: At the end of the experiment, you will be asked to complete a post-experiment questionnaire, which will take 15 to 20 minutes.

6. Compensation: You will be compensated with cash and will sign a receipt of your compensation.

Risks

There are no major risks involved in this experiment, the tasks are not physiologically demanding or psychologically stressing. However, we want to make you aware of two possible risks:

1. The possibility of simulator sickness (a form of motion sickness specific to simulators). Especially upon first using a driving simulator, there is a small chance of feeling dizzy, nauseous, or fatigued. If you feel any of these symptoms appear, please immediately stop the experiment and inform the investigator. The investigator will also monitor for any signs of simulator sickness.

2. You may experience discomfort when wearing the electrodes for heart rate and skin conductance. The electrodes have an approximate 1” radius, and are attached to the skin through an adhesive surface. Adhesives are safe for skin contact, and adhesive residue is removable by wiping with paper towel, or washing with soap and water if necessary. You

will be provided with a paper towel and wet wipes to clean your skin. Disposable adhesive pads will be used during the experiment.

Benefits

There are several benefits to conducting this study. The most important benefit is your contribution to research in traffic safety, which will guide the development of methods to encourage long-term improvements in driver performance. You will also gain experience with academic research and be able to use and test out a state of the art driving simulator.

Compensation

The experiment is expected to last for approximately three hours. At the end, you will receive payment at the rate of $14/hr, plus up to $8 in bonus for good driving performance. Hence, the maximum total compensation is $50 ($14/hr x 3hr + $8 bonus).

You may withdraw from the study at any time. If a withdrawal should occur, you will be compensated on a pro-rated basis at $14 per hour for your involvement to that point. Compensation will be pro-rated to the next half-hour increment. You will not receive a performance bonus if you choose to withdraw before the experiment is completed.

Confidentiality

All information obtained during the study will be held in strict confidence. You will be identified with a study number only, and this study number will only be identifiable by the investigators. No names or identifying information will be used in any publication or presentation. No information identifying you will be transferred outside our research facilities.

Please be advised that we video-record the experimental trials with two web-cameras. One will capture the pedals, and the other will capture the overall scene (including the steering wheel, the dashboard and the secondary task display). We will use several other cameras to track and record where you are looking during the experiment. The videos will only be seen by the primary investigator, as well as co-investigators and faculty supervisor's research assistants and research collaborators. Faces will be blurred in any video used in public presentations.

( ) I consent to having my video released for publications and public presentations

( ) I DO NOT consent to having my video released for publications and public presentations

Participation

Your participation is voluntary, and you may refuse to participate, may withdraw at any time, and may decline to answer any question or participate in any parts of the procedures/tasks – all without negative consequences. If you choose to withdraw at any point during the experiment, your data will be deleted. Only your name will be kept on record.

Location

The experiment will be conducted in the Human Factors and Applied Statistics Lab, located at Rosebrugh Building (RS), 164 College Street, Toronto, ON M5S 3G8.

Questions

You can contact the Office of Research Ethics at ethics.review@utoronto.ca, or 416-946-3273, if you have questions about your rights as a participant. If you have any general questions about this study, please call 647-995-4236 or email hedengbo@mie.utoronto.ca

Consent

I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time. I have received a signed copy of this consent form. I voluntarily consent to participate in this study

______________________________	____________________	____________________
Participant's Name (please print)	Signature	Date

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

______________________________	____________________	____________________
Investigator's Name	Signature	Date

Appendix G: Consent Form for Drivers with Secondary Task

Participant Consent Form

Title: Simulator experiment on driving behavior

Investigators: **Prof. Birsen Donmez, PhD PEng | Associate Professor**

Department of Mechanical & Industrial Engineering
Faculty of Applied Science & Engineering | University of Toronto

Tel: 416-978-7399 Email: donmez@mie.utoronto.ca

Mr. Dengbo He, PhD Candidate

Department of Mechanical & Industrial Engineering
Faculty of Applied Science & Engineering | University of Toronto

Tel: 647-995-4236 Email: hedengbo@mie.utoronto.ca

You are being asked to take part in a research study. Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, discomforts, risks and precautions associated with this study. In order to decide whether you wish to participate or withdraw in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the investigator to explain any words you don't understand before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this document.

Purpose

This study aims to understand driver's behavior under specific conditions. As a participant you will be asked to:

- Fill out a series of questionnaires
- Wear measurement devices on your body
- Drive through a simulated environment

Procedure

There are 6 parts to this study:

1. Screening and Recruitment: You were asked to fill out a screening questionnaire to provide information on your driving history and habits. Based on this information, your eligibility was assessed, and you were invited to take part in this research study.

2. Orientation and Training: You will be provided with written and verbal information on the experiment and its procedures. You will then be trained using the driving simulator and doing a non-driving secondary task. This part will take about 25 min.

3. Equipment Calibration: An eye tracking system (measuring glance location), heart rate and skin conductance (or sweat) sensors, and video cameras are used in this experiment. These systems will be calibrated. The heart rate and skin conductance electrodes will be placed on your body. This part will take about 15 min.

4. Experimental Drives: You will complete 5 drives in the simulator, each about 10 minutes long. You will also be asked to conduct a non-driving secondary task similar to infotainment system interactions that drivers perform in their real vehicles (e.g., radio search). After each drive, you will be asked to complete a questionnaire, which takes about 5 minutes. You will be given a 5-minute break before the next drive. The experimental drives overall will take about 100 min.

5. Post-experiment Questionnaire: At the end of the experiment, you will be asked to complete a post-experiment questionnaire, which will take 15 to 20 minutes.

6. Compensation: You will be compensated with cash and will sign a receipt of your compensation.

Risks

There are no major risks involved in this experiment, the tasks are not physiologically demanding or psychologically stressing. However, we want to make you aware of two possible risks:

1. The possibility of simulator sickness (a form of motion sickness specific to simulators). Especially upon first using a driving simulator, there is a small chance of feeling dizzy, nauseous, or fatigued. If you feel any of these symptoms appear, please immediately stop the experiment and inform the investigator. The investigator will also monitor for any signs of simulator sickness.

2. You may experience discomfort when wearing the electrodes for heart rate and skin conductance. The electrodes have an approximate 1” radius, and are attached to the skin through an adhesive surface. Adhesives are safe for skin contact, and adhesive residue is removable by wiping with paper towel, or washing with soap and water if necessary. You will be provided with a paper towel and wet wipes to clean your skin. Disposable adhesive pads will be used during the experiment.

Benefits

There are several benefits to conducting this study. The most important benefit is your contribution to research in traffic safety, which will guide the development of methods to encourage long-term improvements in driver performance. You will also gain experience with academic research and be able to use and test out a state of the art driving simulator.

Compensation

The experiment is expected to last for approximately three hours. At the end, you will receive payment at the rate of $14/hr, plus up to $8 in bonus for good driving performance and your performance on the secondary task. Hence, the maximum total compensation is $50 ($14/hr x 3hr + $8 bonus).

You may withdraw from the study at any time. If a withdrawal should occur, you will be compensated on a pro-rated basis at $14 per hour for your involvement to that point. Compensation will be pro-rated to the next half-hour increment. You will not receive a performance bonus if you choose to withdraw before the experiment is completed.

Confidentiality

All information obtained during the study will be held in strict confidence. You will be identified with a study number only, and this study number will only be identifiable by the investigators. No names or identifying information will be used in any publication or presentation. No information identifying you will be transferred outside our research facilities.

Please be advised that we video-record the experimental trials with two web-cameras. One will capture the pedals, and the other will capture the overall scene (including the steering wheel, the dashboard and the secondary task display). We will use several other cameras to track and record where you are looking during the experiment. The videos will only be seen by the primary investigator, as well as co-investigators and faculty supervisor's research assistants and research collaborators. Faces will be blurred in any video used in public presentations.

( ) I consent to having my video released for publications and public presentations

( ) I DO NOT consent to having my video released for publications and public presentations

Participation

Your participation is voluntary, and you may refuse to participate, may withdraw at any time, and may decline to answer any question or participate in any parts of the procedures/tasks – all without negative consequences. If you choose to withdraw at any point during the experiment, your data will be deleted. Only your name will be kept on record.

Location

The experiment will be conducted in the Human Factors and Applied Statistics Lab, located at Rosebrugh Building (RS), 164 College Street, Toronto, ON M5S 3G8.

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Consent

I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time. I have received a signed copy of this consent form. I voluntarily consent to participate in this study

_____________________________ ____________________ ____________________

Participant's Name (please print) Signature Date

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

_____________________________ ____________________ ____________________

Investigator's Name Signature Date

Appendix H: NASA Task Load Index (NASA-TLX)

Part 1. Scaling

NASA TLX is a tool used to assess subjective workload of a task. The subscales used in this tool to rate workload include mental demand, physical demand, temporal demand, own performance, effort and frustration. The purpose of this questionnaire is to assess your subjective workload while you drive the last driving scenario.

If you need clarification on a question, please do not hesitate to ask the experimenters. Thank you for your time!

The definition of the subscales used in this questionnaire are as follows. They will appear again while you are doing the following questionnaire.

· Mental Demand - How much mental or perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching etc.?) Was the task easy or demanding, simple or complex?

· Physical Demand - How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating etc.?)

· Temporal Demand - How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

· Own Performance - How stressful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?

· Effort - How hard did you have to work (mentally and physically) to accomplish your level of performance?

· Frustration Level - How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Please keep these definitions in mind while you assign the rates and weights in the following questionnaires.

1) Mental Demand - How much mental or perceptual activity was required (e.g., thinking,

deciding, calculating, remembering, looking, searching etc.?) Was the task easy or demanding, simple or complex?

Question: How mentally demanding was the task?

Very Low Very High*

1 ________________________[__]_____________________________ 20

2) Physical Demand - How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating etc.?)

Question: How physically demanding was the task?

Very Low *Very High* *

1 ________________________[__]_____________________________ 20

3) Temporal Demand - How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Question: How hurried or rushed was the pace of the task?

Very Low *Very High**

1 ________________________[__]_____________________________ 20

4) Performance - How stressful do you think you were in accomplishing the goals of the task? How satisfied were you with your performance in accomplishing these goals?

Question: How successfully were you in accomplishing what you were asked to do? (BE CAREFUL, THE BAR IS FROM Perfect to FAILURE from LEFT to END for this question)

Perfect *Failure**

1 ________________________[__]_____________________________ 20

5) Effort - How hard did you have to work (mentally and physically) to accomplish your level of performance?

Question: How hard did you have to work to accomplish your level of performance?

Very Low *Very High**

1 ________________________[__]_____________________________ 20

6) Frustration Level - How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Question: How insecure, discouraged, irritated, stressed and annoyed were you?

Very Low *Very High**

1 ________________________[__]_____________________________ 20

Part2: Pair Comparison

Now please examine the following pairs of the subscales. For each pair, highlight the element that you feel contributes to the workload more when you did the last drive.

7) ( ) Mental Demand ( ) Physical Demand

8) ( ) Mental Demand ( ) Temporal Demand

9) ( ) Mental Demand ( ) Performance

10) ( ) Mental Demand ( ) Effort

11) ( ) Mental Demand ( ) Frustration

12) ( ) Physical Demand ( ) Temporal Demand

13) ( ) Physical Demand ( ) Performance

14) ( ) Physical Demand ( ) Effort

15) ( ) Physical Demand ( ) Frustration

16) ( ) Temporal Demand ( ) Performance

17) ( ) Temporal Demand ( ) Effort

18) ( ) Temporal Demand ( ) Frustration

19) ( ) Performance ( ) Effort

20) ( ) Performance ( ) Frustration

21) ( ) Effort ( ) Frustration

Appendix I: Risk Perception Questionnaire

The scenario you just drove was As Risky As:

( ) 10: driving with my eyes closed; A crash is bound to occur every time I do this
( ) 9: passing a school bus that has its red lights flashing and the stop arm in full view
( ) 8: driving just under the legal alcohol limit with observed weaving in the lane
( ) 7: in between 6 & 8
( ) 6: driving 20 miles per hour faster than traffic on an expressway
( ) 5: in between 4 & 6
( ) 4: driving 10 miles an hour faster than traffic on an expressway
( ) 3: in between 2 & 4
( ) 2: driving on an average road under average conditions
( ) 1: driving on an easy road with no traffic, pedestrians, or animals while perfectly alert

Appendix J: Situation Awareness Rating Technique (SART)

Situation Awareness is defined as "timely knowledge of what is happening as you drive."

Situation Awareness Rating Technique (SART)	
DEMAND	
Instability of Situation	Likeliness of situation to change suddenly
Variability of Situation	Number of variables which require your attention
Complexity of Situation	Degree of complication (number of closely connected parts) of the situation
SUPPLY	
Arousal	Degree to which you are ready for activity
Spare Mental Capacity	Amount of mental ability available to apply to new tasks
Concentration	Degree to which your thoughts are brought to bear on the situation
Division of Attention	Amount of division of your attention in the situation
UNDERSTANDING	
Information Quantity	Amount of knowledge received and understood
Information Quality	Degree of goodness or value of knowledge communicated
Familiarity	Degree of acquaintance with the situation

Rate the level of each component of situation awareness that you had when you drive. Choose the appropriate number for each component of situation awareness.

DEMAND

Instability of situation: Low 1---------2---------3---------4---------5---------6---------7 High

Variability of situation: Low 1---------2---------3---------4---------5---------6---------7 High

Complexity of situation: Low 1---------2---------3---------4---------5---------6---------7 High

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SUPPLY

Arousal: Low 1---------2---------3---------4---------5---------6---------7 High

Spare mental capacity: Low 1---------2---------3---------4---------5---------6---------7 High

Concentration: Low 1---------2---------3---------4---------5---------6---------7 High

Division of attention: Low 1---------2---------3---------4---------5---------6---------7 High

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UNDERSTANDING

Information quantity: Low 1---------2---------3---------4---------5---------6---------7 High

Information quality: Low 1---------2---------3---------4---------5---------6---------7 High

Familiarity: Low 1---------2---------3---------4---------5---------6---------7 High

Appendix K: Checklist for Trust between People and Automation

Please fill out the questionnaire below for the automated vehicle system you experienced in the last scenario (i.e., combined adaptive cruise control and lane keeping assistance).
Please move the sliders to the point that best describes your feeling or your impression on the following statements.

(Note: not at all=1; extremely=7)
1) I am confident in the system
    1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7
2) The system provides security
    1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7
3) The system is dependable
    1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7
4) The system is reliable
    1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7
5) I can trust the system
    1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7
6) I understand the system
    1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7
7) I feel comfortable engaging in a secondary task when the automation is on
    1 --- 2 --- 3 --- 4 --- 5 --- 6 --- 7

Appendix L: System Acceptance Questionnaire

Please fill out the questionnaire below for the automated vehicle system you experienced in the last scenario (i.e., combined adaptive cruise control and lane keeping assistance).
Please move the sliders to the point that best describes your feeling or your impression on the following statements.

I find the system:

1 Useful	1 --- 2 --- 3 --- 4 --- 5	Useless
2 Pleasant	1 --- 2 --- 3 --- 4 --- 5	Unpleasant
3 Bad	1 --- 2 --- 3 --- 4 --- 5	Good
4 Nice	1 --- 2 --- 3 --- 4 --- 5	Annoying
5 Effective	1 --- 2 --- 3 --- 4 --- 5	Superfluous
6 Irritating	1 --- 2 --- 3 --- 4 --- 5	Likeable
7 Assisting	1 --- 2 --- 3 --- 4 --- 5	Worthless
8 Undesirable	1 --- 2 --- 3 --- 4 --- 5	Desirable
9 Raising Alertness	1 --- 2 --- 3 --- 4 --- 5	Sleep-inducing

Appendix M: Self-Reported Anticipatory Driving Behaviors for Experiment 1

Questionnaire for the 2nd Drive (Scenario: slow tractor)

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized (leave those unrecognized blank) in the scenario by numbering the items from the earliest (starts from 1) to latest:

___ Tractor ahead of the cars
___ Emergency flasher on tractor
___ Brake light of lead vehicle
___ Brake lights of several cars ahead

Please indicate if the following statements apply to you:

___ I was surprised when some of the cars started braking, but then realized all cars behind must brake too
___ I was surprised when the car directly ahead braked
___ I realized the tractor was going significantly slower than the cars
___ I expected the car ahead of me to brake because of the tractor
___ I had consciously released the gas pedal prior to the car ahead of me braking
___ I had depressed the brake pedal prior to the car ahead of me braking

Questionnaire for the 3rd Drive (Scenario: slow truck and car on the right)

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized (leave those unrecognized blank) in the scenario by numbering the items from the earliest (starts from 1) to latest:

___ Slow speed of truck
___ Decreasing distance between truck and car
___ Left turn signal of car

Please indicate if the following statements apply to you:

___ I was expecting the car to stay behind the truck and let me pass
___ I was expecting the car to change lanes and accelerate much earlier
___ I was surprised when the car merged left
___ I was expecting to be cut off by the car
___ I had released the accelerator to provide space for the cars to merge left
___ I tried to accelerate in order to pass the car before it could change lanes

Questionnaire for the 4th Drive (Scenario: vehicle behind cutting ahead)

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized (leave those unrecognized blank) in the scenario by numbering the items from the earliest (starts from 1) to latest:

___ The vehicle behind was approaching you fast
___ The left turning signal of the approaching vehicle

___ The approaching vehicle pulled into the opposite lane
___ An oncoming vehicle appeared on the opposite lane
___ The right signal of the cutting vehicle

Please indicate if the following statements apply to you:

___ I was surprised when the approaching vehicle pulled into the opposite lane
___ I realized that the vehicle behind was trying to pass me through the opposite lane
___ I realized that the passing vehicle had to cut in front of me because of the oncoming vehicle on the opposite lane
___ I was surprised that the passing vehicle cut directly in front of me
___ I consciously released the accelerator prior to the right signal of the passing vehicle
___ I depressed the brake pedal prior to the right signal of the passing vehicle

Questionnaire for the 5th Drive (Scenario: stranded vehicle on the shoulder)

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized (leave those unrecognized blank) in the scenario by numbering the items from the earliest (starts from 1) to latest:

___ Stranded truck
___ Hazard flasher on truck
___ Police cars with hazard flasher on the shoulder behind the truck
___ Brake light of lead vehicles
___ Brake light of several vehicles in front of you
___ Merging of the lead vehicle from right to left lane
___ Merging of several cars in front of you from right to left lane
___ Left turn signal of the lead vehicle
___ Left turn signals of several vehicles in front of you

Please indicate if the following statements apply to you:

___ I was expecting the vehicles in front to slow down
___ I was expecting the vehicles in the right lane to merge into the left lane
___ I was surprised when the vehicle ahead of me braked
___ I had consciously released the gas pedal prior to the vehicle ahead of me braked
___ I had applied the brake pedal prior to the vehicle ahead of me braking
___ I had signaled left before the vehicle ahead of me signaled left

Appendix N: Self-Reported Anticipatory Driving Behaviors for Experiment 2

Questionnaire for the 2nd Drive (Scenario: slow tractor)

Do you remember this scenario? (If no, please ask experimenters for further information before proceeding to next questions.)

___ Yes
___No

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized in the scenario by numbering the items from the earliest (starting from 1) to the latest.
You may ask experimenters if you cannot recall which scenario this one is.

___Tractor ahead of the cars
___Emergency flasher on tractor
___ Brake light of lead car
___Brake lights of several cars ahead

Please indicate if the following statements apply to you:

___ I was surprised when some of the cars started braking, but then realized all cars behind must brake too
___ I was surprised when the car directly ahead braked
___ I realized the tractor was going significantly slower than the cars
___ I expected the car ahead of me to brake because of the tractor
___ I had consciously reduced the speed (by releasing the gas pedal if the automated system is not activated at the moment, depressing the brake pedal, or reducing the set speed of the automated system) prior to the car ahead of me braking

Questionnaire for the 3rd Drive (Scenario: slow truck and car on the right)

Do you remember this scenario? (If no, please ask experimenters for further information before proceeding to next questions.)

___ Yes
___No

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized in the scenario by numbering the items from the earliest (starting from 1) to the latest.
You may ask experimenters if you cannot recall which scenario this one is.

___ Slow speed of truck
___ Decreasing distance between truck and car
___ Left turn signal of car

Please indicate if the following statements apply to you:

___ I was expecting the car to stay behind the truck and let me pass before it signals left
___ I was expecting the car to change lanes and accelerate before it signals left
___ I was surprised when the car merged left
___ I was expecting to be cut off by the car before it signals left
___ I had consciously reduced the speed (by releasing the gas pedal if the automated system is not activated at the moment, depressing the brake pedal, or reducing the set speed of the automated system) to provide space for the car to merge left prior to the left signal of it
___ I tried to accelerate (by depressing the gas pedal, or increasing the set speed of the automated system) in order to pass the car before it signaled left

Questionnaire for the 4th Drive (Scenario: vehicle behind cutting ahead)

Do you remember this scenario? (If no, please ask experimenters for further information before proceeding to next questions.)

___ Yes
___No

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized in the scenario by numbering the items from the earliest (starting from 1) to the latest.
You may ask experimenters if you cannot recall which scenario this one is.

___ The car behind was approaching you fast
___ The left turning signal of the approaching car
___ The approaching car pulled into the opposite lane
___ An oncoming truck appeared on the opposite lane
___ The right signal of the cutting car

Please indicate if the following statements apply to you:

___ I was surprised when the approaching car pulled into the opposite lane
___ I realized that the car behind was trying to pass me through the opposite lane before it signals right
___ I realized that the passing car had to cut in front of me before it signals right because of the oncoming car on the opposite lane
___ I was surprised that the passing car cut directly in front of me
___ I had consciously reduced speed (by releasing the gas pedal if the automated system is not activated at the moment, depressing the brake pedal, or reducing the set speed of the automated system) to provide space for the car to merge in front of me prior to the right signal of it
___ I increased speed (by depressing the gas pedal, or increasing the set speed of the automated system) to prevent it from cutting in front of me prior to the right signal of the passing car

Questionnaire for the 5th Drive (Scenario: stranded vehicle on the shoulder)

Do you remember this scenario? (If no, please ask experimenters for further information before proceeding to next questions.)

___ Yes
___No

Within the scenario you drove earlier, please go through the list below and indicate all items you recognized in the scenario by numbering the items from the earliest (starting from 1) to the latest.
You may ask experimenters if you cannot recall which scenario this one is.

___ Stranded truck
___ Hazard flasher on truck
___ Police cars with hazard flasher on the shoulder behind the truck
___ Brake light of lead cars
___ Brake light of several cars in front of you
___ Merging of the lead car from right to left lane
___ Merging of several cars in front of you from right to left lane
___ Left turn signal of the lead car
___ Left turn signals of several cars in front of you

Please indicate if the following statements apply to you:

___I was expecting the cars in front to slow down before it brakes
___ I was expecting the cars in the right lane to merge into the left lane before it signals left
___ I was surprised when the car ahead of me braked
___ I had consciously reduced speed (by releasing the gas pedal if the automated system is not activated at the moment, depressing the brake pedal, or reducing the set speed of the automated system) prior to the car ahead of me braked
___I had signaled left before the car ahead of me signaled left
___ I had started merging left (and deactivated the lane keeping system) before the car ahead of me signaled left

Appendix O: Manchester Driver Behavior Questionnaire

Nobody is perfect. Even the best drivers make mistakes, do foolish things, or bend the rules at some time or another. For each item below you are asked to indicate HOW OFTEN, if at all, this kind of thing has happened to you. Base your judgments on what you remember of your driving. Please indicate your judgments by circling ONE of the options next to each item. Remember we do not expect exact answers, merely your best guess; so please do not spend too much time on any one item.

1. How often do you do each of the following?

<u>Never</u>, <u>Hardly ever</u>, <u>Occasionally</u>, <u>Quite Often</u>, <u>Frequently</u>, <u>Nearly all the time</u>

a. Try to pass another car that is signaling a left turn.
b. Select a wrong turn lane when approaching an intersection.
c. Failed to "stop" or "yield" at a sign, almost hit a car that has the right of way.
d. Missread signs and miss your exit.
e. Fail to notice pedestrians crossing when turning onto a side street.
f. Drive very close to a car in front of you as a signal that they should go faster or get out of the way.
g. Forget where you parked your car in a parking lot.
h. When preparing to turn from a side road onto a main road, you pay too much attention to the traffic on the main road so that you nearly hit the car in front of you.
i. When you back up, you hit something that you did not observe before but was there.
j. Pass through an intersection even though you know that the traffic light has turned yellow and may go red.
k. When making a turn, you almost hit a cyclist or pedestrian who has come up on your right side.
l. Ignore speed limits late at night or very early in the morning.
m. Forget that your lights are on high beam until another driver flashes his headlights at you.
n. Fail to check your rear-view mirror before pulling out and changing lanes.
o. Have a strong dislike of a particular type of driver, and indicate your dislike by any means that you can.
p. Become impatient with a slow driver in the left lane and pass on the right.
q. Underestimate the speed of an oncoming vehicle when passing.
r. Switch on one thing, for example, the headlights, when you meant to switch on something else, for example, the windshield wipers.
s. Brake too quickly on a slippery road, or turn your steering wheel in the wrong direction while skidding.
t. You intend to drive to destination A, but you 'wake up' to find yourself on the road to destination B, perhaps because B is your more usual destination.
u. Drive even though you realize that your blood alcohol may be over the legal limit.
v. Get involved in spontaneous, or spur-of-the moment, races with other drivers.
w. Realize that you cannot clearly remember the road you were just driving on.
x. You get angry at the behavior of another driver and you chase that driver so that you can give him/her a piece of your mind.

Appendix P: Susceptibility to Driver Distraction Questionnaire (SDDQ)

Please answer the following questions using:
Never; Rarely; Sometimes; Often; Very Often

1. When driving, I …

a. Have phone conversations.
b. Manually interact with a phone (e.g., sending text messages).
c. Adjust the settings of in-vehicle technology (e.g., radio channel or song selection).
d. Read roadside advertisements.
e. Continually check roadside accident scenes if there are any.
f. Chat with passengers if you have them.
g. Daydream.

Please answer the following questions using:
Strongly Disagree; Disagree; Neutral; Agree; Strongly Agree

2. I think it is alright for me to drive and…

a. Have phone conversations.
b. Manually interact with a phone (e.g., sending text messages).
c. Adjust the settings of in-vehicle technology (e.g., radio channel or song selection).
d. Read roadside advertisements.
e. Continually check roadside accident scenes.
f. Chat with passengers.

3. I believe I can drive well even I…

a. Have phone conversations.
b. Manually interact with a phone (e.g., sending text messages).
c. Adjust the settings of in-vehicle technology (e.g., radio channel or song selection).
d. Read roadside advertisements.
e. Continuously check roadside accident scenes.
f. Chat with passengers.

4. Most drivers around me drive and…

a. Have phone conversations.
b. Manually interact with phones.
c. Adjust the settings of in-vehicle technology (e.g., radio channel or song selection).
d. Read roadside advertisements.
e. Continuously check roadside accident scenes.
f. Chat with passengers if there are any.

5. Most people who are important to me think, it is alright for me to drive and...

a. Have phone conversations.
b. Manually interact with phones.
c. Adjust the settings of in-vehicle technology (e.g., radio channel or song selection).
d. Read roadside advertisements.

e. Continuously check roadside accident scenes.
f. Chat with passengers.
Please answer the following questions using:
Never; Rarely; Sometimes; Often; Very Often; Never Happens

6. While driving, I find it distracting when...
a. My phone is ringing.
b. I receive an alert from my phone (e.g., incoming text message).
c. I am listening to music.
d. I am listening to talk radio.
e. There are roadside advertisements.
f. There are roadside accident scenes.
g. A passenger speaks to me.
h. Daydreaming.

Appendix Q: Demographics Information

The following are standard questions that allow researchers to determine how representative the group of participants in a study is of the general population. Remember, filling out this questionnaire is voluntary. Skipping any question that makes you feel uncomfortable will not exclude you from the study.

1. Please describe the highest level of formal education you have completed:
    a. Some high school or less
    b. High school graduate
    c. Some college
    d. College graduate
    e. Some graduate education
    f. Completed graduate or professional degree (e.g. Masters, LCSW, JD, Ph.D., MD, etc.)
2. Are you: (Please circle all that apply.)
    a. A full time student
    b. A part time student
    c. Unemployed
    d. Retired
    e. Employed full time
    f. Employed part time
    g. A full time caregiver (e.g. children or elder)
    h. A part time caregiver (e.g. children or elder)
    i. None of the above
3. Are you:
    a. Married
    b. Divorced
    c. Widowed
    d. Single living with partner
    e. Single never married
    f. Prefer not to answer
4. What best describes your total household income?
    a. Less than $25,000
    b. $25,000 – $49,999
    c. $50,000 – $74,999
    d. $75,000 – $99,999
    e. $100,000 – $124,999
    f. $125,000 – $149,999
    g. $150,000 or more
    h. I don’t know
5. Please provide the city and province where you drive most often:

    City:______________________

    Province:___________________

Appendix R: Complacency-Potential Factors

1. I think that automated devices used in medicine, such as CT scans and ultrasound, provide very reliable medical diagnosis.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
2. Automated devices in medicine save time and money in the diagnosis and treatment of disease.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
3. If I need to have a tumor in my body removed, I would choose to undergo computer-aided surgery using laser technology because it is more reliable and safer than manual surgery.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
4. Automated systems used in modern aircraft, such as the automatic landing system, have made air journeys safer.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
5. ATMs provide a safeguard against the inappropriate use of an individual's bank account by dishonest people.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
6. Automated devices used in aviation and banking have made work easier for both employees and customers.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
7. Even though the automatic cruise control in my car is set at a speed below the speed limit, I worry when I pass a police radar speed trap in case the automatic control is not working properly.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
8. I would rather purchase an item using a computer than have to deal with a sales representative on the phone because my order is more likely to be correct using the computer.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
9. Bank transactions have become safer with the introduction of computer technology for the transfer of funds.
   Strongly Disagree 1---2---3---4---5 Strongly Agree
10. I feel safer depositing my money at an ATM than with a human teller.
   Strongly Disagree 1---2---3---4---5 Strongly Agree

Appendix S: Steps and Scripts in Experiment 1

Pre-participant Setup

1. Turn on computers – Main Cab, MiniSim, VidCap, and D-Lab
   MiniSim Computer Password: minsim.UT2012
   D-Lab Computer Password: birsendonmez

2. Prepare physiological sensors (GSR, ECG)
   1. Test batteries for power level for physiological sensors
   2. Insert batteries into the main unit
   3. Attach the ISO interface to the main unit (on the end labeled recorder)
   4. Attach the input box to the main unit (the input box will be used as a dock for the sensors later)
   5. Attach the Serial port to USB converter to the ISO interface (on the end labeled PC)
   6. Plug the USB converter to the D-lab computer (USB port at the back of the unit)

3. Prepare the head-mounted eye-tracking system:
   1. Connect the power and all the cable to D-Lab Computer through USB 3.0 port
   2. Stabilize all the cable using tapes
   3. Attach the wide lens on head-mounted eye-tracker

3. Make sure the miniSim scenarios for the participant is ready: they should be in Desktop/DengboExp1/[*Scenario number.name*].

4. Start MiniSim (v2.2) softwares
Note: To add a new participant: Minisim2.2/data/Rcm_data/experimentconfig.txt
   1. Change instructions.txt and routeTable.txt (make sure to back up the original)
      C:\NadsMiniSim_2.2\data\DesfaultCabSound\Instructs
      C:\NadsMiniSim_2.2\bin.x64
   2. Make sure all components are functioning normally (green indicator for all parts)
   3. Make sure the right experiment and participant are selected, and data collection mode is turned ON

5. On D-Lab computer, run Desktop/init_DengboExp1.bat **as administrator**
Note: This should start D-Lab, the Java program (forwards frame# to D-Lab), and Change the directory of D-Lab to DengboExp1. You need to hit "Enter" after each step.
Note note: ***At the step saying "Starting D-Lab", wait until D-Lab is fully started before hit "Enter" and go to the next step.*** *(Or this script will fail at starting the Java program.)*

6. Setup D-Lab for this study
   1. In D-Lab's starting screen, choose "Available studies > DengboExp1" folder
   2. Create a new participant in the right folder (e.g. P03)
   3. Check the following for recording: 3-Logitech cameras, Frame Number, ECG, GSR and eye-tracking system

9. Have receipts, consent form, work load/between drive questionnaire (on iPad) ready.

Meeting with the Participant

1. Introduce yourself.

2. Tell the participant where to put their personal belongings (in a designated area outside the experimental room or on top of the cabinet in the simulator room).

3. Tell participant to remove their watch and to silence their phones.

4. Request that they put their watch/electronics devices with their belongings or that you could hold on to it for them. They can have access to them during breaks.

5. Tell the participant that participation is voluntary and that they can choose not to participate.

6. Ask participant how much **sleep** they have had and **how alert they feel today**. (Ask participant when was the last time they had **alcohol**?) Ask participant for **driver license** for confirmation.

7. Provide participant with written and verbal information regarding experiment and procedures.

8. Provide participants with consent form; offer to answer any questions regarding the consent form.

9. If they desire to participate, have participant sign the consent form.

10. Tell the participant that they are free to withdraw at any time without penalty, but they will only be paid based on the amount of time completed.

For those in groups WITHOUT secondary tasks:
"The experiment will last about 3 hours in total and consisted of a practice drive and 5 short drives. During each drive, your main task is to drive normally and safely. The lead vehicles may brake suddenly during the drive. The extra bonus will be depended on your driving performance. You may withdraw any time during the experiment and be paid according to how much time you have been through the experiment. If you have more questions, please let us know."

For those in groups WITH secondary tasks:
"The experiment will last about 3 hours in total and consisted of a practice drive and 5 short drives. During each drive, your main task is to drive normally and safely. The lead vehicles may brake suddenly during the drive. At the same time, you are allowed to do a secondary task while driving. The extra bonus will be depended on your driving performance and the correctness of the secondary task. You will earn 20 cents for each correct answer you make and loss 40 cents for each incorrect answer you make during secondary task. You will be given an introduction and a practice of the secondary task later. You may withdraw any time during the experiment and be paid according to how much time you have been through the experiment. If you have more questions, please let us know."

Practice Drive

1. Ask the participant to adjust the seat and steering wheel so that the participant is sitting in a comfortable position (steering wheel adjustment is on left side of steering wheel and seat adjustment is under the seat at the front).

2. Instruct the participant to sit in the chair at relatively stable position throughout the session. Inform them that the driving session will last for approximately 1.5 hours.

<u>"Please have a seat in the driver's seat. You may adjust the seat or steering wheel so that you are comfortable. The total driving task will be about 1.5 hour, while you may stay on the seat when answering surveys in between drives."</u>

3. Make sure they are clear about the driving tasks and give Introduction to practice drive:
<u>"Now you will go through a practice drive. It will last about 5 to 10 minutes depending on how you feel about driving on the simulator. During the whole experiment, the speed limit for rural road is 50 mph, for ramp is 35 mph and for highway is 60 mph. Again, your bonus will depend on your driving performance. Please try your best to drive around the speed limit.</u>

4. Inform the participant of simulation sickness and let the participant know that if they feel sick or nauseous at any time that they should stop the experiment and drive.
Driving while holding head static and eyes fixed to the front can be an indicator of simulator sickness. They do not feel their best in the simulator and that you want to know if the participant feels any symptoms.
<u>"Some people may experience simulation sickness. It takes time to adapt. Simulator sickness does not get better if you try to 'tough it out'. So please let us know if you feel uncomfortable."</u>

5. After 5 minutes drive, ask the participant:

- Do they need more practice?
- Do they feel dizzy? (simulation sickness). If yes, follow the following procedures:
  At first sights of simulator sickness
  1. Pause the drive / put in park
  2. Shut eyes
  3. Put a foot on the floor
  4. Perform slow head turning (while seated) first with eyes shut, then open
  5. Have water, mess basin, towelettes available
  6. Rest 5 minutes, brief walk, accompany subject
  7. Reinitiate or discontinue experiment

6. Once the participant finishes the previous portion, have them stop and put the car in park. Then stop the simulator.

Secondary Task Training (for secondary task group only)

Provide the participant with the in-laboratory "Discover Project Mission" task training and let them practice on Surface.

<u>"You are allowed to perform a word matching task on the Surface for all following drives. Your task will be to select a phrase out of 10 phrases that matches the phrase 'Discover Project</u>

Missions'. A phrase qualifies as a match if it has either 'discover' first, "Project" second, or "Missions" third. For example, "Discover Missions Project" is a match because it has "Discover" first, whereas "Project Discover Misguide" is not a match because none of the target words are in the correct place. There is only one correct answer in the list of 10 candidate phrases and you can use the up and down arrows to scroll through the options. Press submit when you have selected the answer. "

"Your bonus will also depend on your driving performance and secondary tasks. you will get 20 cents for each correct choice you make and loss 40 cents for each incorrect answer your make. The minimum bonus is $0 and maximum bonus is $8."

Target phrases:
"Discover Project Missions"

Some examples:
"Project Missions Discover"
"Missions Project Discover"
"Disguise Product Missions"
"Disguise Product Misses"

Sensor Setup with Participant

1. Help put sensors on the participants (in the order of: ECG, GSR)
2. Attach all three sensors to the input box
3. Check in D-Lab to see if all the sensors are connected properly

Head-Mounted Eye Tracker Configuration

1. Tell participant that they will be required to undergo the eye calibration test.
"Before we begin the experiment, we will need to undergo an eye tracker calibration to capture the information about where you are looking on the simulator"

2. Follow the head-mounted eye-tracking procedures in D-Lab

Run Scenarios

1. Inform the participants of the driving task and answer any questions that the participants have

Script for 1st Scenario
""Now, the experiment starts. Your main task in this study will be the safe operation of the vehicle. Please drive as you would in your own vehicles. Remember, the speed limit for rural road is 50 mph, for ramp is 35 mph and for highway is 60 mph. Please ignore the speed sign in all scenarios because of the malfunction of the system. A record will let you know when you should turn at the intersection. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep right on highway when possible. (You are allowed to perform the secondary task on the Surface.) Remember, driving safety is your first priority. Your bonus for the experiment will depend on your driving performance (and your secondary task performance)." Please ALSO PAY ATTENTION TO REAR-VIEW MIRRORS as you would do in daily drive.

Script for 2nd Scenario
"Now we will drive the second scenario. In this drive, you will drive on a rural road. The speed limit is 50 mph, you should drive around the speed limit. Please don't pass leading vehicles and fall too much behind the stream of traffic. (You are allowed to perform the secondary task on the Surface.) Remember, driving safety is your first priority. Your bonus for the experiment will depend on your driving performance (and your secondary task performance)."

Script for 3rd Scenario
"Now we will drive the third scenario. In this drive, you will drive on a highway. The speed limit is 60 mph, you should drive around the speed limit. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep left on highway when possible. (You are allowed to perform the secondary task on the Surface.) Remember, driving safety is your first priority. Your bonus for the experiment will depend on your driving performance (and your secondary task performance)."

Script for 4th Scenario
"Now we will drive the forth scenario. In this drive, you will drive on a rural road. The speed limit is 50 mph, you should drive around the speed limit. Please don't pass leading vehicles and fall too much behind the stream of traffic. (You are allowed to perform the secondary task on the Surface.) Remember, driving safety is your first priority. Your bonus for the experiment will depend on your driving performance (and your secondary task performance)."

Script for 5th Scenario
"Now we will drive the third scenario. In this drive, you will drive on a highway. The speed limit is 60 mph, you should drive around the speed limit. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep right on highway when possible. (You are allowed to perform the secondary task on the Surface.) Remember, driving safety is your first priority. Your bonus for the experiment will depend on your driving performance (and your secondary task performance)."

2. Setup and start ALL the recordings:

Be upfront about not talking during the experiment.

a. Import scenario
b. Start recording data on D-Lab. **Remember to rename the recording name for D-Lab and MiniSim files when possible**, or it might overwrite previous recording.
d. Click start drive in MiniSim
e. Keep the LED lights in the room on

3. Stop D-Lab recording, stop the drive in miniSim.

4. Ask the participants to finish the within experiment questionnaire on iPad (except for the 1st drive)

"Please think about your workload and how you feel during the last drive and fill out this questionnaire. Afterwards, you can take a short break before continuing with the rest of the drives."

5. Always ask if the participant needs a break in between drives to walk around and get water etc before starting next drive.
<u>"How are you feeling? Do you need a break?"</u>

6. Always keep an eye on the signals to make sure the sensors are working well.

End of the Experiment
1. Ask them to finish the post-drive questionnaire on iPad.
2. Once they finish all the drives, thank them for their time and ask if they have any final questions or comments.
3. Fill out a receipt form based on the number of hours taken. ($15/hr + $5 for completion).

Wrap up Experiment
1. Discard adhesive pads
2. Provide participant with paper towel to clean residual jell from sensors
3. Return sensors to proper locations and wrap up head-mounted eye tracker
5. Revert files: instructions.txt and routeTable.txt
6. Revert volume level
7. Shut off computers
8. Check battery levels for all equipment

Appendix T: Steps and Scripts in Experiment 2

Pre-participant Setup

1. Turn on computers – Main Cab, MiniSim, VidCap, and D-Lab
   MiniSim Computer Password: minsim.UT2012
   D-Lab Computer Password: birsendonmez

2. Prepare physiological sensors (GSR, ECG)
   1. Test batteries for power level for physiological sensors
   2. Insert batteries into the main unit
   3. Attach the ISO interface to the main unit (on the end labeled recorder)
   4. Attach the input box to the main unit (the input box will be used as a dock for the sensors later)
   5. Attach the Serial port to USB converter to the ISO interface (on the end labeled PC)
   6. Plug the USB converter to the D-lab computer (USB port at the back of the unit)

3. Prepare the head-mounted eye-tracking system:
   1. Connect the power and all the cable to D-Lab Computer through USB 3.0 port
   2. Stabilize all the cable using tapes
   3. Attach the wide lens on head-mounted eye-tracker

3. Make sure the miniSim scenarios for the participant is ready: they should be in Desktop/DengboExp2/[*Scenario number.name*].

4. Start MiniSim (v2.2) softwares

Note: To add a new participant: Minisim2.2/data/Rcm_data/experimentconfig.txt

   1. Change instructions.txt and routeTable.txt (make sure to back up the original)
      C:\NadsMiniSim_2.2\data\DesfaultCabSound\Instructs
      C:\NadsMiniSim_2.2\bin.x64
   2. Make sure all components are functioning normally (green indicator for all parts)
   3. Make sure the right experiment and participant are selected, and data collection mode is turned ON

5. On D-Lab computer, run Desktop/init_DengboExp2.bat **as administrator**

Note: This should start D-Lab, the Java program (forwards frame# to D-Lab), and Change the directory of D-Lab to DengboExp2. You need to hit "Enter" after each step.

Note note: ***At the step saying "Starting D-Lab", wait until D-Lab is fully started before hit "Enter" and go to the next step.*** *(Or this script will fail at starting the Java program.)*

6. Setup D-Lab for this study
   1. In D-Lab's starting screen, choose "Available studies > DengboExp2" folder
   2. Create a new participant in the right folder (e.g. P03)
   3. Check the following for recording: 3-Logitech cameras, Frame Number, ECG, GSR and eye-tracking system

7. Have receipts, consent form, work load/between drive questionnaire (on iPad) ready.

Meeting with the Participant

1. Introduce yourself.

2. Tell the participant where to put their personal belongings (in a designated area outside the experimental room or in the experiment room).

3. Tell participant to remove their watch and to turn their phone to silent or flight mode.

4. Request that they put their watch/electronics devices with their belongings or in the drawer next to the seat. They can have access to them during breaks.

5. Ask participant how much **sleep** they have had and **how alert they feel today**. (Ask participant when was the last time they had **alcohol**?) Ask participant for **driver license** for confirmation.

6. Provide participant with consent form, written and verbal information regarding experiment and procedures and offer to answer any questions regarding the consent form.

7. If they agree to participate, have participant sign the consent form.

8. Tell the participant that they are free to withdraw at any time without penalty, but they will only be paid based on the amount of time completed.

"The experiment will take about 3 hours in total and consisted of 2 practice drives and five short experimental drives. The compensation you will get will be consisted of two parts: first part is time-based, which is $ 14 per hour and in total 42 dollars as long as you finish the whole experiment; the second part is performance-based, which is $ 8 maximum and will be depended on your driving performance (as well as the secondary task performance).

As mentioned before, you may withdraw anytime during the experiment and be paid according to how much time you have been through the experiment. However, if you withdraw without finishing the experiment, you will not get performance-based bonus. So far, do you have any questions?"

Secondary Task Training (for secondary task group only)

Provide the participant with the in-laboratory "Discover Project Mission" task training and let them practice on Surface.

"As mentioned before, you are allowed to perform a word matching task on the Surface for all the following drives. Your task will be to select one phrase out of 10 phrases that matches the target phrase 'Discover Project Missions'. A phrase qualifies as a match if it has either 'discover' first, "Project" second, or "Missions" third. For example,

"Discover Missions Project"

("Discover Project Missions" — Target)

is a match because it has "Discover" at the first place, whereas

"Project Discover Misguide"
("Discover Project Missions", as comparison)

is not a match because none of the target words are in the correct place. There is only one correct answer in the list of 10 candidate phrases and you can use the up and down arrows to scroll through the options. And you may press submit when a phrase is selected. "

"As mentioned before, your bonus will be depended on your driving performance and secondary task correctness. you will get 20 cents for each correct choice you make and loss 40 cents for each incorrect answer your make. The minimum bonus is $0 and maximum bonus is $8."

"Please select the correct phrases out of the following four phrases and let me know"

Target phrases:
"Discover Project Missions"

Some examples:
"Project Missions Discover"
"Missions Project Discover"
"Disguise Product Missions"
"Disguise Product Misses"

"Now, you may practise doing the secondary on the Surface."

Practice Drive: Manual and automated driving
1. Ask the participant to adjust the seat and steering wheel so that the participant is sitting in a comfortable position (steering wheel adjustment is on left side of steering wheel and seat adjustment is under the seat and to the right front corner).

"Now please adjust the driver's seat. You may adjust the seat or steering wheel so that you feel comfortable about the position of the steering wheel and the seat."

2. Give introduction of the driving system in the simulator. Start "training1".
"Although this experiment is about automated driving, in the experiment, you may also need to drive by yourself when necessary. So, first, I am going to tell how to drive the vehicle in the simulator. Basically, you can operate the vehicle as you would always do in a real vehicle. You have two pedals under the dashboard and you are supposed to use the turning signals when necessary (point to the left stick) and of course, you need to steer using the steering wheel. However, you don't need to use the gear stick during the whole experiment. Also, there will be two sides mirrors on these two screens and a rear-view mirror in the middle screen. You may need to scan them as you would do in a real vehicle. You will have a chance to practise driving by yourself without automation later. Do you have any questions now?"

3. Give instructions on automated driving:
"As mentioned, although you may drive by yourself with automated systems off, in this experiment, you should always use the automated driving system when possible. So, right now, I am going to let you know how to use the automated systems in the simulator.

The automated system we are going to use in this experiment is consisted of two parts: the lane keeping and adaptive cruise control. First, please be informed that you don't need to use the buttons covered by the white tapes. You only need to use the buttons that are not covered.

Lane keeping system can keep the vehicle in the middle of the lane and follow the route. **To activate** lane keeping, you just need to press this button (point the button). And **to cancel it**, you can either press the button again or steer the steering wheel. Remember, you may need to do it manually if you need to make a turn in the intersections. Now you can try engage and disengage the lane keeping system.

Limits: you may need to pay attention that 1) the LKA may not work when making a turn at the intersection. 2) the LKA may not work when the lane marks are less visible. Now, can you repeat the two limitations of the LKA? (If not, repeat until participants remember it.)

The Adaptive Cruise Control, i.e., ACC can maintain a set speed of your vehicle when possible or keep a safe distance with the leading vehicle when there are vehicles in front of you, whichever is slower. In another word, if the set speed is faster than the speed of the vehicles in front of you, it will slow down your vehicle to keep a safe distance from the lead vehicles. In our experiment, the ACC is always ready. So, **to use the system,** you may just need to press the "set button" (point to the button) to get it **engaged**. When you press the "set button", ACC will use your current speed as the set speed, the ACC icon on the dashboard will turn green, and the set speed will be displayed here. Another way to engage the ACC is to use the RES button. If will use your last set speed as the set speed of the ACC. When the system is engaged, you may press the up arrow (point to the button) to **increase the speed** and the down arrow (point to the button) to **decrease the speed**. For each time you press the arrows, the speed would change by 2mph. **To deactivate** the system, you can either press this button (point to the button) or depress the braking pedal. Now you can try engage and disengage the ACC system.

Limits: you may need to pay attention that 1) if the vehicle is getting too close to the lead vehicle (for example, because of the intensive brake of the lead vehicle), the ACC system may not be able to decelerate fast enough to keep a safe distance. 2) ACC may not able to recognize stationary objects or vehicles. So you are still responsible for the safe operation of the vehicle. Now, can you repeat the 2 situations that ACC may not work? (If not, repeat until participants remember it.)

Because of the functionality of the system, sometimes, when the speed deceased too much, vehicle speed may drop to 0 for a moment. You don't need to do anything, the system will increase and catch up with the lead vehicle in a moment.

Right now, do you have any questions?"

4. Make sure they are clear about the driving tasks and give Introduction to practice drive (Using "training 2"):
"Now you will go through a practice drive. It will last about 10 minutes depending on how you feel about driving on the simulator. It includes two stages: in the first stage, you are required to drive by yourself without lane keeping and ACC.

After 5 minutes of drive, you will be instructed to get familiar with automated driving functions. In this stage, you need to engage and disengage the lane keeping and ACC twice and keep using the system for around 3 minutes.

During the whole experiment, the speed limit 50 mph for rural road, 60 mph for highway. I will let you know which road it is. Because of the functionality of the simulator, you may find some incorrect speed limit signs along the road, you may just ignore them, they have nothing to do with the experiment. Please try your best to drive around the speed limit as I just told you.

(For secondary task group), remember, in this practise drive, you are encouraged to also practise doing secondary task when you feel confident and safe to do so in the whole practice drive. The correctness in this practise drive will not be counted for your final bonus. But please keep doing the task such that we can tell you have got what the task is"

5. Inform the participant of simulation sickness and let the participant know that if they feel sick or nauseous at any time that they should stop the experiment and drive.
Driving while holding head static and eyes fixed to the front can be an indicator of simulator sickness. They do not feel their best in the simulator and that you want to know if the participant feels any symptoms.
"There is one more thing you may need to pay special attention. Some people may experience simulation sickness and it does not get better even if you try to 'tough it out'. So please let us know if you feel uncomfortable and I will stop the experiment immediately.

Now, please press the brake first and start driving when you are ready."

6. After five minutes of manual driving, start automated system practise.
"Now you may practice using the automated system.
First, please engage the ACC system and adjust the set speed.
Now, please engage the lane keeping.
Now, please **disengage** the ACC system using braking pedal.
Now please **disengage** the and keeping system using steering wheel, for example, change to the other lane.
Good, now please engage the ACC and lane keeping system again.
Now please **disengage** the ACC using the buttons.
Now please **disengage** the lane keeping system using the buttons.
Good, now, please feel free to practise engaging and disengaging the ACC and lane keeping systems for the rest of this practise drive.
(for secondary task group), please do remember to practice doing secondary task when you feel safe to do so."

7. After practice minutes drive, ask the participant:

- Do they need more practice?
- Do they feel dizzy? (simulation sickness). If yes, follow the following procedures:
  At first sights of simulator sickness
  1. Pause the drive / put in park
  2. Shut eyes
  3. Put a foot on the floor
  4. Perform slow head turning (while seated) first with eyes shut, then open
  5. Have water, mess basin, towelettes available
  6. Rest 5 minutes, brief walk, accompany subject
  7. Reinitiate or discontinue experiment

Sensor Setup with Participant

1. Help put sensors on the participants (in the order of: ECG, GSR)
2. Attach all three sensors to the input box
3. Check in D-Lab to see if all the sensors are connected properly

"Now we will put on three physiological sensors on your body. They are heart rate sensors, which will be three pads on your chest; Skin conductivity sensors, which will be two pads under your left foot and eye gaze position tracking sensor, which will be this head-mounted eye tracker. We may put some conductive jam on your body, they can be removed later using the alcohol pads."

Head-Mounted Eye Tracker Configuration

1\. Tell participant that they will be required to undergo the eye calibration test.
"Before we begin the experiment, we will need to undergo an eye tracker calibration to monitor where you are looking at on the simulator"

2\. Follow the head-mounted eye-tracking procedures in D-Lab

Run Scenarios

1\. Inform the participants of the driving task and answer any questions that the participants have

Script for 1st
""Now, the experiment starts. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and lane keeping system at the beginning of the drive and keep the automated driving system on when possible. I said when possible, it means in most of the time, you could use the system, but in case of emergency, you are still supposed to be responsible for the safety of the drive and take-over if necessary. Remember, the speed limit for rural road is 50 mph and for highway is 60 mph. Please set the ACC around the speed limit. I will let you know when you should turn at the intersection. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep right on highway when possible.
(For secondary task group) You are allowed to perform the secondary task on the Surface when you feel safe to do so.
Remember, driving safety is your first priority. Your bonus for this drive and the following drives will depend on your driving performance
(For secondary task group) and your secondary task performance."

Script for 2nd Scenario

"Now we will drive the second scenario. In this drive, you will drive on a rural road. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving system on when possible. The speed limit is 50 mph. Please set the ACC speed around the speed limit. Please don't pass leading vehicles and fall too much behind the stream of traffic.

(For secondary task group) You are allowed to perform the secondary task on the Surface when you feel safe to do so."

Script for 3rd Scenario

"Now we will drive the third scenario. In this drive, you will drive on a highway. Your main drive in this study will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving system on when possible. The speed limit is 60 mph. Please set the ACC speed around the speed limit. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep left on highway when possible.

(For secondary task group) You are allowed to perform the secondary task on the Surface when you feel safe to do so."

Script for 4th Scenario

"Now we will drive the forth scenario. In this drive, you will drive on a rural road. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving system on when possible. The speed limit is 50 mph. Please set the ACC speed around the speed limit. Please don't pass leading vehicles and fall too much behind the stream of traffic.

(For secondary task group) You are allowed to perform the secondary task on the Surface when you feel safe to do so."

Script for 5th Scenario

"Now we will drive the third scenario. In this drive, you will drive on a highway. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving system on when possible. The speed limit is 60 mph. Please set the ACC speed around the speed limit. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep right on highway when possible.

(For secondary task group) You are allowed to perform the secondary task on the Surface when you feel safe to do so."

2. Setup and start ALL the recordings:

Be upfront about not talking during the experiment.

a. Import scenario
b. Start recording data on D-Lab. **Remember to rename the recording name for D-Lab and MiniSim files when possible**, or it might overwrite previous recording.
d. Click start drive in MiniSim
e. Turn on the LED light strips

3. Stop D-Lab recording, stop the drive in miniSim.

4. Ask the participants to finish the within experiment questionnaire on iPad (except for the 1st drive)

"Please think about your workload and how you feel during the last drive and fill out this questionnaire. Afterwards, you can take a short break before next drive."

5. Always ask if the participant needs a break in between drives before starting next drive.

6. Always keep an eye on the signals to make sure the sensors are working well.

End of the Experiment

1. Ask them to finish the post-drive questionnaire on iPad.

"That's all the drives, thank you very much! Now please take off all the sensors and you may take a seat outside. You need to finish one more post-experiment questionnaire, which is going to last around 15 minutes. Please feel free to ask me to explain anything in the questionnaire, if you have any questions or anything you feel unclear. After the questionnaire, you will get your compensation for the experiment."

2. Once they finish all the drives, thank them for their time and ask if they have any final questions or comments.

3. Fill out a receipt form based on the number of hours taken. ($14/hr + $8 for completion).

Wrap up Experiment

1. Discard adhesive pads and clean the devices using the alcohol pads.
2. Provide participant with paper towel to clean residual jell from sensors
3. Return sensors to proper locations and wrap up head-mounted eye tracker
5. Revert files: instructions.txt and routeTable.txt
6. Revert volume level
7. Shut off computers
8. Check battery levels for all equipment

Appendix U: Steps and Scripts in Experiment 3

Pre-participant Setup

1. Turn on computers – Main Cab, MiniSim, VidCap, and D-Lab
   MiniSim Computer Password: minsim.UT2012
   D-Lab Computer Password: birsendonmez

2. Prepare the head-mounted eye-tracking system:
   1. Connect the power and all the cable to D-Lab Computer through USB 3.0 port

3. Make sure the miniSim scenarios for the participant is ready: they should be in Desktop/DengboExp3/[Display Types]/[*Scenario number.name*].

4. Start MiniSim (v2.2.1) softwares

Note: To add a new participant: Minisim2.2.1/data/Rcm_data/experimentconfig.txt

   1. [Optional] Change instructions.txt and routeTable.txt (make sure to back up the original)
      C:\NadsMiniSim_2.2.1\data\DesfaultCabSound\Instructs
      C:\NadsMiniSim_2.2.1\bin.x64
   2. Make sure all components are functioning normally (green indicator for all parts)
   3. Make sure the right experiment and participant are selected, and data collection mode is turned ON
   4. Set the volume to 30 in Windows.

5. Start video cap following the instructions on the desktop of the video cap computer.

6. On D-Lab computer, run Desktop/init_DengboExp3.bat **as administrator**

Note: This should start D-Lab, the Java program (forwards frame# to D-Lab), and Change the directory of D-Lab to DengboExp3. You need to hit "Enter" after each step.
Note note: ***At the step saying "Starting D-Lab", wait until D-Lab is fully started before hit "Enter" and go to the next step.*** *(Or this script will fail at starting the Java program.)*

7. Setup D-Lab for this study
   1. In D-Lab's starting screen, choose "Available studies > DengboExp3" folder
   2. Create a new participant in the right folder (e.g. P03)
   3. Check the following for recording: Frame Number and eye-tracking system

8. Have receipts, consent form, work load/between drive questionnaire (on iPad) ready.

Meeting with the Participant

1. Introduce yourself.

2. Tell the participant where to put their personal belongings (in a designated area outside the experimental room or in the experiment room).

3. Tell participant to remove their watch and to turn their phone to silent or flight mode. Request that they put their watch/electronics devices with their belongings or in the drawer next to the seat. They can have access to them during breaks.

4. Ask participant how much **sleep** they have had and **how alert they feel today**. (Ask participant when was the last time they had **alcohol**?). Ask participant for **driver license** for confirmation.

5. Provide participant with consent form, written and verbal information regarding experiment and procedures and offer to answer any questions regarding the consent form.

6. If they agree to participate, have participant sign the consent form.

7. Tell the participant that they are free to withdraw at any time without penalty, but they will only be paid based on the amount of time completed.

“The experiment will take about 3 hours in total and consisted of 2 practice drives and 5 short experimental drives. The compensation you will get will be consisted of two parts: first part is time-based, which is $ 14 per hour and in total 42 dollars as long as you finish the whole experiment; the second part is performance-based, which is $ 8 maximum and will be depended on your driving performance as well as the secondary task performance.

As mentioned before, you may withdraw anytime during the experiment and be paid according to how much time you have been through the experiment. However, if you withdraw without finishing the experiment, you will not get performance-based bonus. So far, do you have any questions?”

Secondary Task Training
Provide the participant with the in-laboratory “Discover Project Mission” task training and let them practice on Surface.

“As mentioned before, you are allowed to perform a word matching task on the Surface for all the following drives. Your task will be to select one phrase out of 10 phrases that matches the target phrase **‘Discover Project Missions’**. A phrase qualifies as a match if it has either ‘discover’ first, “Project” second, or “Missions” third. For example,

“Discover Missions Project”

is a match because it has “Discover” at the first place, whereas

“Project Discover Misguide”

is not a match because none of the target words are in the correct place.

“Here are some examples below. Please select the correct phrases out of the following four phrases and let me know”

Target phrases:
"Discover Project Missions"

Some examples:
"Project Missions Discover"
"Missions Project Discover"
"Disguise Product Missions"
"Disguise Product Misses"

"In each question, there is only one correct answer in the list of 10 candidate phrases but each time, only 2 phrases will be displayed. So you will have to use the up and down arrows to scroll through the options. And you may press submit when a phrase is selected."

"As mentioned before, your bonus will be depended on your driving performance and secondary task correctness. you will get 20 cents for each correct choice you make and loss 40 cents for each incorrect answer your make. The minimum bonus is $0 and maximum bonus is $8."

"Now, you may practise doing the secondary on the Surface."

Practice Drive: Manual and automated driving

1. Ask the participant to adjust the seat and steering wheel so that the participant is sitting in a comfortable position (steering wheel adjustment is on left side of steering wheel and seat adjustment is under the seat and to the right front corner).

"Now please adjust the driver's seat. You may adjust the seat or steering wheel so that you feel comfortable about the position of the steering wheel and the seat."

2. Give introduction of the driving system in the simulator. Start "training1".

"Although this experiment is about automated driving, in the experiment, you may also need to drive by yourself when necessary. So, first, I am going to give an introduction of how to drive the vehicle manually in the simulator. Basically, you can operate the vehicle as in a real vehicle. You have two pedals under the dashboard and you are supposed to use the turning signals when necessary (point to the left stick) and of course, you need to steer using the steering wheel. However, you don't need to use the gear stick during the whole experiment. Also, there will be two sides mirrors on these two screens and a rear-view mirror in the middle screen. You may need to scan them as you would do in a real vehicle. You will have a chance to practise. Do you have any questions so far?"

3. Give instructions on automated driving:

"As mentioned, although you may drive by yourself without the automated driving systems, in this experiment, you should always use the automated driving system when possible. So, right now, I am going to show you how to use the automated systems in the simulator.

The automated driving system we are going to use in this experiment is consisted of two parts: the lane keeping and adaptive cruise control system. First, please be informed that you don't need to use the buttons covered by the white tapes. You only need to use the buttons that are not covered.

Lane keeping system can keep the vehicle in the middle of the lane and follow the route. **To activate** lane keeping, you just need to press this button (point the button). And **to cancel it**, you can either press the button again or steer the steering wheel. When the system is working, you will see two green lines in the dashboard.

Limits: you may need to pay attention that the LKA may not work when the lane marks are less visible.

The Adaptive Cruise Control, i.e., ACC can maintain a set speed of your vehicle when possible or keep a safe distance with the leading vehicle when there are vehicles in front of you, whichever is slower. In another word, if the set speed of ACC is faster than the speed of the vehicles in front of you, it will slow down your vehicle to keep a safe distance from the lead vehicles. T**o use the system,** you may just need to press the "set button" (point to the button) to get it **engaged**. When you press the "set button", ACC will use your current speed as the set speed, the ACC icon on the dashboard will turn green, and the set speed will be displayed here. Another way to engage the ACC is to use the RES button. It will use your last set speed as the set speed of the ACC. When the system is engaged, you may press the up arrow (point to the button) to **increase the speed** and the down arrow (point to the button) to **decrease the speed**. For each time you press the arrows, the speed would change by 2mph. **To deactivate** the system, you can either press this button (point to the button) or depress the braking pedal. Now you can try engage and disengage the ACC system.

Limits: you may need to pay attention that if the vehicle is getting too close to the lead vehicle the lead vehicle brakes too intensively, the ACC system may not be able to decelerate fast enough to keep a safe distance.

Right now, do you have any questions?"

4. Make sure they are clear about the driving tasks and give Introduction to practice drive (Using "Driving Training.scn"):

"Now you will go through a practice drive. It will last about 10 minutes depending on how you feel about driving on the simulator. It includes two stages: in the first stage, you are required to drive by yourself without the automated systems.

After 5 minutes of drive, you will be instructed to get familiar with automated driving functions. In this stage, you need to engage and disengage the lane keeping and ACC twice and keep using the system for around 3 minutes.

During the whole experiment, the speed limit is 50 mph for rural road, 60 mph for highway. I will let you know which road it is. Please drive at the speed limit as I just told you.

Remember, in this practise drive, you are encouraged to also practise doing secondary task when you feel confident and safe to do so.

5. Inform the participant of simulation sickness and let the participant know that if they feel sick or nauseous at any time that they should stop the experiment and drive.

Driving while holding head static and eyes fixed to the front can be an indicator of simulator sickness. They do not feel their best in the simulator and that you want to know if the participant feels any symptoms.
"There is one more thing you may need to pay special attention. Some people may experience simulation sickness and it does not get better even if you try to 'tough it out'. So please let us know if you feel uncomfortable and I will stop the experiment immediately.

Now, please press the brake first and start driving when you are ready."

6. After five minutes of manual driving, start automated system practise.

"Now you may practice using the automated system. I am going to ask you to engage and disengage the systems. You don't have to do the actions immediately if you are not confident about the traffic situations.
First, please engage the ACC system and adjust the set speed.
Now, please engage the lane keeping.
Now, please **disengage** the ACC system using braking pedal.
Now please **disengage** the and keeping system using steering wheel, for example, change to the other lane.
Good, now please engage the ACC and lane keeping system again.
Now please **disengage** the ACC using the buttons.
Now please **disengage** the lane keeping system using the buttons.
Good, now, please feel free to practise engaging and disengaging the ACC and lane keeping systems for the rest of this practise drive.
(for secondary task group), please do remember to practice doing secondary task when you feel safe to do so."

7. After practice minutes drive, ask the participant:
   - Do they need more practice?
   - Do they feel dizzy? (simulation sickness). If yes, follow the following procedures:
     At first sights of simulator sickness
     1. Pause the drive / put in park
     2. Shut eyes
     3. Put a foot on the floor
     4. Perform slow head turning (while seated) first with eyes shut, then open
     5. Have water, mess basin, towelettes available
     6. Rest 5 minutes, brief walk, accompany subject
     7. Reinitiate or discontinue experiment

Display Training (for Baseline)

AR Displays

"Now I am going to introduce another feature of the system. This simulator is equipped with a system that is able to show the status of the automation in front of the vehicle.

When the LKA is engaged, you will see 2 green lines in front of the vehicle; when it is off, the indicators will disappear.

Also, when the ACC is engaged, you will see green indicators in front of the vehicle and when it is off, the indicators will disappear."

"So far, do you have any questions?"

"Now, you will do 1 more practise drive to get familiar with the displays. And remember, to use both the ACC and lane keeping in this drive. If you have any questions, please let me know. You don't need to do the secondary task in this practise drive. At the same time, in this drive, please don't take any actions in any cases and you just need to observe the displays."

Display Training (for Display A)

Automation Limits Displays

"Now I am going to introduce some of the additional features of the automated driving systems. That is: the automated driving system is equipped with an AR display that can show the status of the Lane Keeping and the ACC systems in front of the vehicle."

"First, the two lines besides the vehicle in the AR display in front of the vehicle show the status of the l**ane keeping system**. If it is green, it means that the lane keeping system has detected the lanes very clearly and it should be safe to let it control the steering wheel."

"When the lines turn red, it means that no lane is detected, you should control the steering wheel by yourself. When you disengage the LKA, the two lines will disappear."

"For the **ACC system,** the system can display the status of the system in 5 levels with 4 indicators in front. First, as we just mentioned, the ACC cannot use the full power of the braking system. It can only decelerate the vehicle at 0.3G. In another word, if there is another vehicle braking intensively in front the your vehicle, the ACC may not be able to stop the vehicle in time if you don't take over."

"If no vehicle is detected ahead, you could see 4 indicators in front of the vehicle indicating the braking distance of the system."

"The furthest indicator shows the safe distance even when the lead vehicles suddenly stops, for example, a rock falling the road."

"The closer indicator shows the safe distance if the lead vehicle brakes intensively."

"Similarly, the next indicator shows the safe distance if the lead vehicle brakes moderately."

"Lastly, the closest indicator shows the safe distance if the lead vehicle brakes slightly."

"In summary, the closer the indicators, the less deceleration the system can deal with."

"Additionally, if the ACC detects there is a braking event but it is within the capability of the ACC, the indicators of the ACC will turn orange. If the braking event is out of the capability of the ACC, the ACC indicators will turn red, there will be a red icon showing in the middle of the screen and there will be an audio warning."

“When you disengage the ACC or LKA, the corresponding displays in front will disappear. (show participants)”

“So far, do you have any questions?”

“Now, you will do 1 more practise drive to get familiar with the displays. And remember, to use both the ACC and lane keeping in this drive. If you have any questions, please let me know. You don’t need to do the secondary task in this practise drive. At the same time, in this drive, please don’t take any actions in any cases and you just need to observe the displays.”

Display Training (for Display B)
Automation Limits Displays
“Now I am going to introduce some of the additional features of the automated driving systems. That is: the automated driving system is equipped with an AR display that can show the status of the Lane Keeping and the ACC systems in front of the vehicle.”

“First, the two lines besides the vehicle in the AR display in front of the vehicle show the status of the l**ane keeping system**. If it is green, it means that the lane keeping system has detected the lanes very clearly and it should be safe to let it control the steering wheel.”

“When the lines turn red, it means that no lane is detected, you should control the steering wheel by yourself. When you disengage the LKA, the two lines will disappear.”

“For the **ACC system,** the system can display the status of the system in 5 levels with 4 indicators in front. First, as we just mentioned, the ACC cannot use the full power of the braking system. It can only decelerate the vehicle at 0.3G. In another word, if there is another vehicle braking intensively in front the your vehicle, the ACC may not be able to stop the vehicle in time if you don’t take over."

“If no vehicle is detected ahead, you could see 4 indicators in front of the vehicle indicating the braking distance of the system.”

“The furthest indicator shows the safe distance even when the lead vehicles suddenly stops, for example, a rock falling the road.”

“The closer indicator shows the safe distance if the lead vehicle brakes intensively.”

“Similarly, the next indicator shows the safe distance if the lead vehicle brakes moderately.”

“Lastly, the closest indicator shows the safe distance if the lead vehicle brakes slightly.”

“In summary, the closer the indicators, the less deceleration the system can deal with.”

“Additionally, if the ACC detects there is a braking event but it is within the capability of the ACC, the indicators of the ACC will turn orange. If the braking event is out of the capability of the ACC, the ACC indicators will turn red, there will be a red icon showing in the middle of the screen and there will be an audio warning."

"When you disengage the ACC or LKA, the corresponding displays in front will disappear. (show participants)"

"So far, do you have any questions?"

Surrounding Traffic Displays
"Now I am going to introduce another feature of the system. Using the connected vehicle technology, the vehicle i can show the surrounding traffic environment and the road agents that matter to your driving safety (e.g., leading vehicle)

For example, it can show on which kind of the road you are driving on.

The first picture shows that you are driving on a 2-lane rural road.
The second picture shows that you are driving on a ramp.

The 3rd picture shows that you are driving on a 4-lane highway, with the two direction separated by double yellow line and the two lanes on the same direction separated by white dash line.

In all these displays, your own vehicle is shown in blue, other vehicles are shown in white and the truck or tractor will be shown in green. You can also see brake light and turning signals of other vehicles in the display.

In addition, the system can show the potential traffic change that matters to driving safety. For example, when you are about to enter the highway through a ramp following a chain of vehicles, it can show a potential chain braking event because there is a yield sign in front.

The yellow dash arrow shows the potential path of other road agents that matters to driving safety and there is a warning sign giving the reason of the change of the traffic situations.

"This information will be shown on the right bottom corner in a bird view."

"So far, do you have any questions?"

"Now, you will do 1 more practise drive to get familiar with the displays. And remember, to use both the ACC and lane keeping in this drive. If you have any questions, please let me know. You don't need to do the secondary task in this practise drive. At the same time, in this drive, please don't take any actions in any cases and you just need to observe the displays."

Head-Mounted Eye Tracker Configuration
1. Tell participant that they will be required to undergo the eye calibration test.
"Before we begin the experiment, we will need to undergo an eye tracker calibration to monitor where you are looking at on the simulator"

2. Follow the head-mounted eye-tracking procedures in D-Lab

3. Remember to restart miniSim between each drive

Run Scenarios

1. Inform the participants of the driving task and answer any questions that the participants have

Script for 1st Scenario

"Now, the experiment starts. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and lane keeping system at the beginning of the drive and keep the automated driving system on when possible. I said when possible, it means in most of the time, you should use the system, but in case of emergency, you are still supposed to be responsible for the safety of the drive and take-over if necessary. Remember, the speed limit for rural road is 50 mph and for highway is 60 mph. Please set the ACC at the speed limit. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep right on highway when possible. You are allowed to perform the secondary task on the Surface when you feel safe to do so.

Remember, driving safety is your first priority. Your bonus for this drive and the following drives will depend on your driving performance and your secondary task performance."

Script for 2nd Scenario

"Now you will drive the second drive. In this drive, you will drive on a rural road. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving system on when possible. The speed limit is 50 mph. Please set the ACC speed at the speed limit. Please don't pass leading vehicles and fall too much behind the stream of traffic. You are allowed to perform the secondary task on the Surface when you feel safe to do so."

Script for 3rd Scenario

"Now you will drive the third scenario. In this drive, you will drive on a highway. Your main drive in this study will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving system on when possible. The speed limit is 60 mph. Please set the ACC speed at the speed limit. Please don't pass leading vehicles, don't fall too much behind the stream of traffic, and keep left on highway when possible. You are allowed to perform the secondary task on the Surface when you feel safe to do so."

Script for 4th Scenario

"Now you will drive the forth scenario. In this drive, you will drive on a rural road. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving systems on when possible. The speed limit is 50 mph. Please set the ACC speed at the speed limit. Please don't pass leading vehicles and fall too much behind the stream of traffic. You are allowed to perform the secondary task on the Surface when you feel safe to do so."

Script for 5th Scenario

“Now we will drive the third scenario. In this drive, you will drive on a highway. Your main task in this drive will be the safe operation of the vehicle. Please engage the ACC and LKA system at the beginning of the drive and keep the automated driving systems on when possible. The speed limit is 60 mph. Please set the ACC speed at the speed limit. Please don’t pass leading vehicles, don’t fall too much behind the stream of traffic, and keep left on highway when possible. You are allowed to perform the secondary task on the Surface when you feel safe to do so.”

2. **Setup and start ALL the recordings:**

Be upfront about not talking during the experiment.

Import scenario

b. Start recording data on D-Lab. **Remember to rename the recording name for D-Lab and MiniSim files when possible**, or it might overwrite previous recording.

d. Click start drive in MiniSim

e. Turn on the LED light strips

3. Stop D-Lab recording, stop the drive in miniSim.

4. Ask the participants to finish the within experiment questionnaire on iPad (except for the 1st drive)

“Please think about your how you feel during the last drive and fill out this questionnaire. Afterwards, you can take a short break before next drive.”

5. Always ask if the participant needs a break in between drives before starting next drive.

6. Always restart miniSim software between each drive.

End of the Experiment

1. Ask them to finish the post-drive questionnaire on iPad.

“That’s all the drives, thank you very much! Now please take off all the sensors and you may take a seat outside. You need to finish one more post-experiment questionnaire, which is going to last around 15 minutes. Please feel free to ask me to explain anything in the questionnaire, if you have any questions or anything you feel unclear. After the questionnaire, you will get your compensation for the experiment.”

2. Once they finish all the drives, thank them for their time and ask if they have any final questions or comments.

3. Fill out a receipt form based on the number of hours taken. ($14/hr + $8 for completion).

4. Provide participant with paper towel to clean residual jell from sensors

5. Wrap up head-mounted eye tracker and shut down computers

Appendix V: Mean Glance Duration and Rate of Glances at the Anticipatory Cues and at the Secondary Task in Experiment 3

Toward the Anticipatory Cues

Dependent Variable	Explanatory Variables	df	F/χ^2	*p*
Mean glance duration (s)	Display (TOR-AC, ST-TOR-AC, and Baseline)	(2, 41.5)	12.85	<.0001*
	Experience (novice vs. experienced)	(1, 41.5)	2.76	.10
	Scenario Criticality (A-N vs. A-not-N)	(1, 44.5)	2.09	.15
	Experience*Display	(2, 41.5)	0.30	.74
	Experience*Scenario Criticality	(1, 44.5)	0.32	.58
	Scenario Criticality * Display	(2, 44.5)	4.76	.01*
Rate of Glances (/min)[1]	Display (TOR-AC, ST-TOR-AC, and Baseline)	2	18.59	<.0001*
	Experience (novice vs. experienced)	1	0.03	.86
	Scenario Criticality (A-N vs. A-not-N)	1	0.25	.62
	Experience*Display	2	3.36	.19
	Experience*Scenario Criticality	1	1.50	.22
	Scenario Criticality * Display	2	0.62	.73

Toward the Secondary Task Display

Mean glance duration (s)	Display (A, B and Baseline)	(2, 39.9)	6.36	.004*
	Experience (novice vs. experienced)	(1, 39.9)	2.04	.16
	Scenario Criticality (A-N vs. A-not-N)	(1, 43.3)	1.24	.27
	Cue-onset (before vs. after-cue-onset)	(1, 43.6)	32.28	<.0001*
	Experience*Display	(2, 40)	0.40	.67
	Experience*Scenario Criticality	(1, 43)	0.19	.67
	Experience*Cue-onset	(1, 43.6)	0.15	.70
	Scenario Criticality*Display	(2, 42.9)	0.14	.87
	Scenario Criticality*Cue-onset	(1, 48.7)	0.08	.78
	Display*Cue-onset	(2, 43.6)	16.37	<.0001*
Rate of glances (/min)[1]	Display (A, B and Baseline)	2	3.33	.19
	Experience (novice vs. experienced)	1	2.24	.13
	Scenario Criticality (A-N vs. A-not-N)	1	0.06	.81
	Cue-onset (before vs. after-cue-onset)	1	30.11	<.0001*
	Experience*Display	2	1.13	.57
	Experience*Scenario Criticality	1	2.01	.16
	Experience*Cue-onset	1	0.00	.97
	Scenario Criticality*Display	2	7.80	.02*
	Scenario Criticality*Cue-onset	1	0.11	.74
	Display*Cue-onset	2	30.57	<.0001*

[1]Test statistic is χ^2.

Appendix W: The results from *Transportation Research* Record (2019) paper that compared the secondary task engagement in Experiments 1 and 2

All statistical models were built in SAS University Edition V9.4. Rate of manual interactions, glance rates, and long glance rates were analyzed through negative binomial regression given that over-dispersion was detected in the count data. Count data follow the Poisson distribution (if the mean is large, Poisson distribution is approximately normal, but for small means this approximation does not hold). The mean and the variance of the Poisson distribution are equal; if there is over-dispersion in the data (i.e., variance > mean), the negative binomial distribution is used. The number of manual interactions, glances, and long glances observed in our dataset were therefore analyzed with a negative binomial regression. Given that there was variability in how long each participant took to complete their drive, the length of each drive was used as the offset variable in our negative binomial models, transforming the model estimates from counts (number) to rates (number per minute). Further, repeated measures (four drives completed by each participant) were accounted through Generalized Estimating Equations. All other variables were analyzed through mixed linear models as the residuals met the model assumptions (e.g., normality), with participant as a random factor (to account for correlated observations) and the variance-covariance structure chosen based on the Bayesian Information Criterion.

Secondary task engagement models focused on the 32 participants who performed the secondary task in the experiment. Thus, these models included experience, experimental phase, and their interaction as predictor variables. Workload and perceived risk analysis included experience, secondary task, experiment phase, and their two-way interactions as predictor variables. Given that the data collection for non-automated vehicle driving in Experiment 1 (Phase 1) was completed before data collection for Experiment 2 automated driving (Phase 2), results comparing non-automated to automated driving are confounded by time of data collection. Rather than performing a qualitative comparison between the findings of the two phases we included phase as a predictor variable to quantify potential differences. However, the readers should be cognizant of this potential confound in interpreting the statistical results generated from the comparisons of the two phases.

Table W1 summarizes the model results. In the table, the model equations for secondary task engagement are presented below, where, Y is the response variable; t is the length of each drive or the offset variable in the negative binomial models; β_1, β_2, and β_3 are the coefficients for predictor variables: x_1 (=1 when Phase 2, 0 otherwise), x_2 (=1 when experienced, 0 otherwise), and $x_1 * x_2$ interaction.

Negative binomial models:

$$\log\left(\frac{\mathrm{E[Y]}}{t}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 * x_2$$

Mixed effects models for fixed factors:

$$\mathrm{E[Y]} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 * x_2$$

The model equation used for workload measures and perceived risk presented below, includes three additional coefficients, β_4,β_5, and β_6, corresponding to secondary task and its two-ways interactions with phase and experience: x_3 (=1 when with secondary task, 0 otherwise), and $x_1 * x_3$ and $x_2 * x_3$ interactions.

$$\mathrm{E[Y]} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 * x_2 + \beta_4 x_3 + \beta_5 x_1 * x_3 + \beta_6 x_2 * x_3$$

In Figures W1 to W6, the boxplots present minimum, first quartile, median, third quartile, and maximum with the bottom whisker, lower edge of the box, bold horizontal line, upper edge of the box, and the top whisker, respectively. Raw data points are indicated with gray dots and the averages are indicated with hollow diamonds. “M” stands for mean and “SD” stands for standard deviation.

Table W1. Model results

Measure	Phase	Experience	Phase *Experience	Model Coefficients $\beta_0, \beta_1, \beta_2, \beta_3$	Secondary Task	Phase* Secondary Task	Experience* Secondary Task	Model Coefficients $\beta_4, \beta_5, \beta_6$
Secondary Task Engagement								
Rate of manual interaction (/min)	$\chi^2(1)=17.82$ $p<.0001$	$\chi^2(1)=1.81$ $p=.2$	$\chi^2(1)=4.31$ $p=.04$	2.20, 0.83, 0.10, -0.55				
Duration of glances (ms)	$F(1,28)=22.55$ $p<.0001$	$F(1,28)=38.31$ $p<.0001$	$F(1,28)=4.92$ $p=.03$	7.85, -0.71, -0.86, 0.45				
Rate of glances (/min)	$\chi^2(1)=2.92$ $p=.09$	$\chi^2(1)=10.91$ $p=.001$	$\chi^2(1)=0.27$ $p=.6$	2.56, -0.11, 0.34, -0.09				
Percent time looking (%)	$F(1,28)=14.06$ $p=.0008$	$F(1,28)=1.97$ $p =.2$	$F(1,28)=1.41$ $p=.2$	0.44, -0.18, -0.10, 0.09				
Rate of long glances (/min)	$\chi^2(1)=10.59$ $p=.001$	$\chi^2(1)=8.41$ $p=.004$	$\chi^2(1)=0.66$ $p=.4$	0.92, 0.82 -1.24, 0.54				
Workload and Perceived Risk								
NASA TLX	$F(1,57)=2.41$ $p=.13$	$F(1,57)=0.14$ $p=.71$	$F(1,57)=2.48$ $p=.12$	5.95, 4.85, 1.40, -2.96	$F(1,57)=8.29$ $p=.006$	$F(1,57)=4.15$ $p=.046$	$F(1,57)=0.21$ $p=.65$	-1.22, -3.83, 0.86
Perceived risk	$F(1,57)=3.83$ $p=.06$	$F(1,57)=0.14$ $p=0.71$	$F(1,57)=1.40$ $p=.24$	3.79, 1.84, 0.37, -0.95	$F(1,57)=23.8$ $p<.0001$	$F(1,57)=2.00$ $p=.16$	$F(1,57)=0.01$ $p=.92$	-1.35, -1.14, - 0.08

- Secondary Task Engagement

An interaction effect was found for rate of manual interactions with the secondary task display ($\chi^2(1) = 4.31$, $p = .04$). As shown in Figure W1, in Phase 1, i.e., Experiment 1 with non-automated driving, there were no differences between novice and experienced drivers ($p = .6$). However, in Phase 2, i.e., Experiment 2 with automation, novice drivers had a 58% higher manual interaction rate with the display compared to the experienced drivers (95% CI: 7%, 133%, $\chi^2(1) = 5.24$, $p = .02$). When comparisons were made across phases, experienced drivers' manual interaction rate did not differ ($p = .09$), whereas novice drivers in Phase 2 who drove with automation had a 131% higher manual interaction rate with the display compared to the novice drivers in Phase 1 who drove manually (95% CI: 55%, 246%, $\chi^2(1) = 16.68$, $p < .0001$).

An interaction effect was also found for average glance duration toward the secondary task display ($F(1, 28) = 4.92$, $p = .03$). As can be seen in Figure W2, experienced drivers had shorter average glance durations than novice drivers in both phases (manual: $t(28) = 2.81$, $p = .009$; automated: $t(28) = 5.95$, $p < .0001$) but the difference between the experienced and novice drivers was bigger with automation. When comparisons were made across phases, experienced drivers' average glance durations did not differ ($p = .08$), whereas novice drivers in Phase 2 who drove with automation had longer average glance durations toward the display compared to the novice drivers in Phase 1 who drove manually ($t(28) = 4.93$, $p < .0001$).

Experienced drivers had a 34% higher rate of glances toward the secondary display than novice drivers (Figure W3, 95% CI: 13%, 60%, $\chi^2(1) = 10.91$, $p = .001$); however, their rate of long glances (> 2 seconds) was 62% lower than novice drivers (Figure W4, 95% CI: 27%, 80%, $\chi^2(1) = 8.41$, $p = .004$). When comparisons were made across phases, rate of long glances (> 2 seconds) were found to be 197% higher in Phase 2 - automation than Phase 1 - manual driving (95% CI: 54%, 473%, $\chi^2(1) = 10.59$, $p = .001$). Percent time looking at the display was also 14% higher in Phase 2 compared to Phase 1 (Figure W5, 95% CI: 6%, 22%, $F(1, 28) = 14.06$, $p = .0008$).

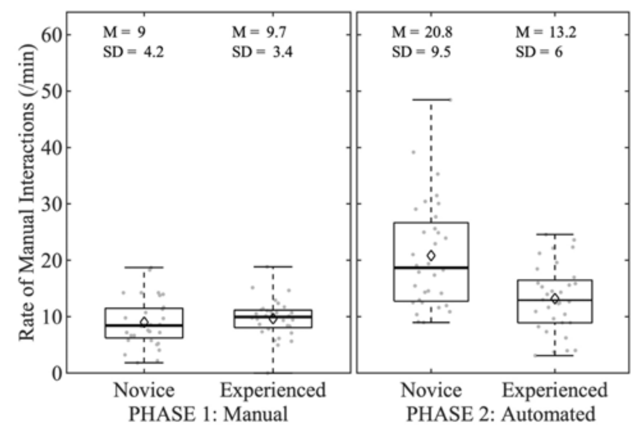

Figure W1. Rate of interaction (per minute) with the secondary task display.

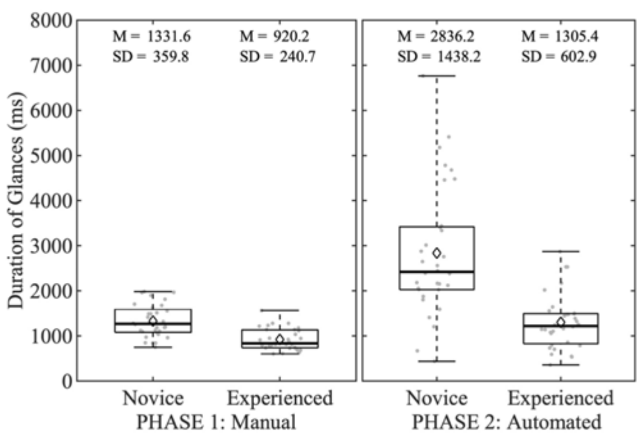

Figure W2. Average glance duration toward secondary task display.

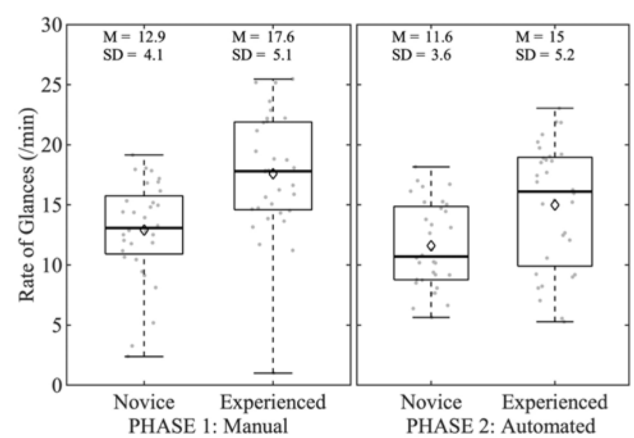

Figure W3. Rate of glances (per minute) toward secondary task display.

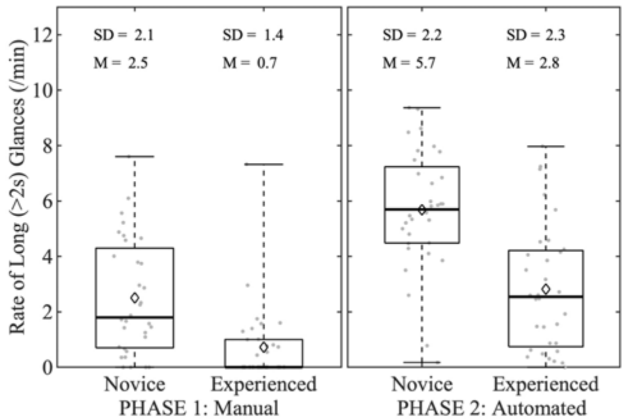

Figure W4. Rate of long (>2 seconds) glances (per minute) toward secondary task display.

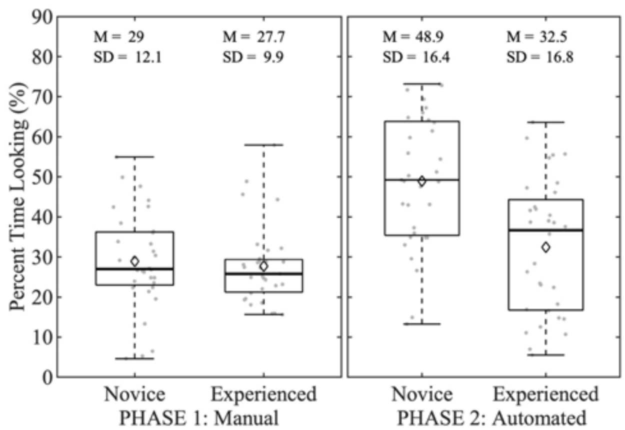

Figure W5. Percent time looking at secondary task display.

- Workload Measures and Perceived Risk

No significant effects were found for galvanic skin responses (GSR) or heart rate (HR), $p > .05$. For NASA-TLX, there was an interaction effect of secondary task and automation (Figure W6, $F(1, 57) = 4.15$, $p = .046$). In Phase 1, the presence of the secondary task increased self-reported workload ($t(57) = 3.48$, $p = .001$); whereas in Phase 2, it had no significant effect on self-reported workload ($p = .6$). When comparisons were made across phases, self-reported workload without secondary task did not differ ($p = .7$), whereas self-reported workload with secondary task decreased with automation ($t(57) = 2.54$, $p = .01$).

There was a main effect of secondary task on perceived risk ($F(1, 57) = 23.67$, $p < .0001$). Drivers in the secondary task conditions self-reported to perceive a higher level of risk compared to those in the no secondary task conditions (mean difference: 1.96, 95 CI% = 1.15, 2.77).

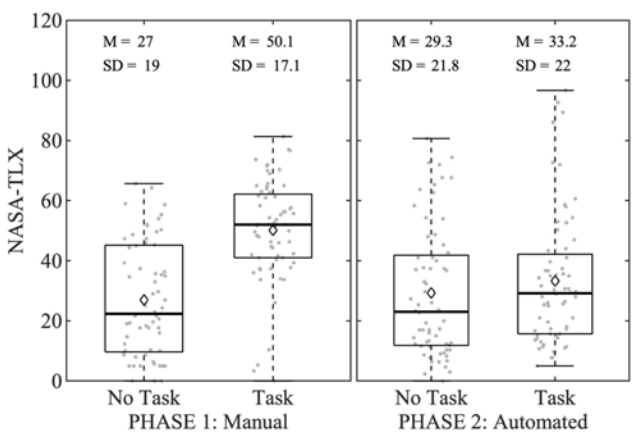

Figure W6. NASA-TLX ratings.