Topic: Surface Transportation

Anticipatory Driving in Automated Vehicles: The Effects of Driving Experience and Distraction

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Abstract

Objective: To understand the influence of driving experience and distraction on drivers' anticipation of upcoming traffic events in automated vehicles. ***Background:*** In non-automated vehicles, experienced drivers spend more time looking at cues that indicate upcoming traffic events compared to novices, and distracted drivers spend less time looking at these cues compared to non-distracted drivers. Further, pre-event actions (i.e., proactive control actions prior to traffic events) are more prevalent among experienced drivers and non-distracted drivers. However, there is a research gap on the combined effects of experience and distraction on driver anticipation in automated vehicles. ***Methods:*** A simulator experiment was conducted with 16 experienced and 16 novice drivers in a vehicle equipped with adaptive cruise control and lane keeping assist systems (resulting in SAE Level-2 driving automation). Half of the participants in each experience group were provided with a self-paced primarily visual-manual secondary task. ***Results:*** Drivers with the task spent less time looking at cues and were less likely to perform anticipatory driving behaviors (i.e., pre-event actions or preparation for pre-event actions such as hovering fingers over the automation disengage button). Experienced drivers exhibited more anticipatory driving behaviors, but their attention towards the cues were similar to novices for both task conditions. ***Conclusion:*** In line with non-automated vehicle research, in automated vehicles, secondary task engagement impedes anticipation while driving experience facilitates anticipation. ***Application:*** Though Level-2 automation can relieve drivers of manually controlling the vehicle and allow engagement in distractions, visual-manual distraction engagement can impede anticipatory driving and should be restricted.

Keywords: Anticipatory driving, Driver distraction, Driving simulator, Visual attention, Driving automation

Precis: In a simulator, we investigated the effect of visual-manual distractions on drivers' anticipation of traffic events among novice and experienced drivers in automated vehicles. The results show that distraction impeded while experience facilitated anticipation. Distraction shifted drivers' attention away from the cues that enable anticipation in both experience conditions.

1 Introduction

With the state-of-the-art vehicle automation technology available to the public, i.e., SAE Level 2 driving automation (SAE On-Road Automated Vehicle Standards Committee, 2018), drivers no longer need to control the vehicle continuously. However, they are still required to monitor the roadway and the automation, and intervene when necessary, either by taking over vehicle control or by adjusting the automation; intervention may be required due to degradations in automation reliability or situations that exceed automation capability. Drivers are expected to perform better if they can anticipate when their intervention is needed. For example, drivers exhibited more stable steering wheel control after a takeover when vehicle automation disengaged on a regular schedule compared to a variable and thus unpredictable one (Merat et al., 2014). Drivers also allocated more attention toward relevant cues within the vehicle and the environment indicating the potential for a takeover: Dogan et al. (2017) found that their participants looked more at the speedometer when they were approaching an upper speed limit of adaptive cruise control (ACC); participants of DeGuzman et al. (2020) glanced more at the roadway when there were breaks in lane markings, a situation that led to Lane Keeping Assist (LKA) failures.

While the above studies suggest that drivers can perform better if they can anticipate when their intervention is needed, the type of scenarios utilized in these studies are fairly simplistic for studying the skill of anticipation. Anticipatory driving has been defined 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. 605). Anticipatory driving goes beyond hazard anticipation and requires relatively complex scenarios, with causal links between the behaviors of different traffic agents, which we refer to as anticipatory scenarios (He & Donmez, 2020). In these scenarios, anticipation can be assessed using various measures, such as behavioral or glance metrics. For example, glancing more towards cues that indicate an upcoming traffic event and disengaging the automation prior to the event suggest that a driver might have anticipated the event. Limited research in automated driving has used anticipatory scenarios to investigate drivers' anticipation of upcoming traffic events. In a driving simulator, Merat and Jamson (2009) found that drivers in non-automated vehicles were better able to anticipate critical (i.e., required driver intervention) lead vehicle braking events than drivers in automated vehicles, as indicated by a faster brake response time. When the lead vehicle braking was due to a traffic light ahead changing from amber to red, drivers in non-automated vehicles braked before the lead vehicle began braking, whereas drivers in automated vehicles did not brake until after. However, this study did not investigate the factors that may influence drivers' anticipation. In a recent simulator study on automated driving, we investigated the effect of in-vehicle displays on novice and experienced drivers' anticipation when they were distracted by a visual-manual secondary task (He et al., 2021), but we did not investigate the combined influence of driving experience and secondary task availability.

Research in non-automated vehicles suggests that experienced drivers are more capable of anticipating upcoming traffic events (He & Donmez, 2020; Stahl et al., 2014, 2019), possibly because they are better at visually scanning the environment (e.g., Jackson et al., 2009; Sagberg & Bjørnskau, 2006) and they pay more attention to environmental cues that enable anticipation of upcoming events (i.e., anticipatory cues) (He & Donmez, 2020; Stahl et al., 2019). While several studies investigated the influence of drivers' experience with automated driving systems on their behaviors in automated vehicles (e.g., Larsson et al., 2014), limited number of studies have focused on general driving experience. Young and Stanton (2007) found that active steering (a lateral support system) led to smoother control of speed and headway among novice drivers, but not among more experienced drivers; He and Donmez (2019) found that experienced drivers exhibited less risky off-road glance behaviors in automated vehicles compared with novices; and He et al. (2021) found that when presented with surrounding traffic information on an in-vehicle display in an automated vehicle, experienced drivers maintained safer margins (longer minimum gap times) compared to novices, despite exhibiting a higher rate of long (>2 s) glances towards a visual-manual secondary task.

Based on the findings from non-automated driving studies (e.g., Stahl et al., 2014, 2019), it is expected that experienced drivers may perform better in monitoring traffic and anticipating upcoming events in automated vehicles. However, the benefit of experience on anticipation may be less pronounced in automated vehicles. As drivers no longer need to control the vehicle continuously when using driving automation, they are expected to have more spare attentional capacity than in non-automated vehicles. This spare attentional capacity may especially aid anticipation among novice drivers, who are known to have limited spare attentional capacity to perceive on-road hazards in non-automated vehicles (Jackson et al., 2009). However, drivers may not allocate this additional spare attentional capacity to the driving task. Previous research found that drivers in automated vehicles are more likely to shift their spare attention onto secondary tasks (de Winter et al., 2014; He & Donmez, 2019; Jamson et al., 2013), which can negatively impact their ability to attend to and respond to upcoming traffic events (He & Donmez, 2018, 2020). The negative effect of a secondary task is expected to be more pronounced among novice drivers, as they were found to engage more in secondary tasks and exhibit riskier glance behaviors compared to experienced drivers in automated vehicles (He & Donmez, 2019).

In this paper, we present a driving simulator experiment to investigate the influence of driving experience and secondary task engagement on anticipation in automated vehicles equipped with ACC and LKA. Participants completed four drives, each with a scenario that enabled anticipation of an upcoming traffic event. For these scenarios, we analyzed glance metrics as well as anticipatory driving behaviors, including proactive control actions prior to an event (i.e., pre-event actions) and preparations for any control actions to change the automation settings or take over control (i.e., pre-event preparation).

2 Method

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. The criteria for the recruitment of novice and experienced drivers are shown in Table 1 and were based on previous research (He & Donmez, 2020; Stahl et al., 2016). Participants were randomly assigned to a secondary task condition, balanced for gender. Considering that visual-manual distractions are the most detrimental to safety in non-automated vehicles (Dingus et al., 2016), a visual-manual secondary task was used. Each participant completed four experimental drives in the simulator with both ACC and LKA working simultaneously. Near the end of each drive, there was a scenario where the participant could anticipate an upcoming traffic event based on the behavior of other traffic agents. In this paper, we focus on these anticipatory scenarios. Secondary task engagement and physiological measures recorded throughout the entire drives, and self-reported workload and perceived risk in the drives were reported in He and Donmez (2019).

Overall, our experimental design is the same as the one used in He and Donmez (2020), except that this earlier study investigated driver anticipation in non-automated vehicles. The driving automation in the current study was designed to be able to navigate all events without intervention from the driver to avoid impacting drivers' attitudes and/or behaviors in an unrealistic way, as driving automation failures are relatively rare in current production systems (Blanco et al., 2016; Favarò et al., 2017; Teoh & Kidd, 2017). However, in addition to verbal instructions about limitations of ACC and LKA, we introduced an ACC failure event (i.e., abrupt intensive lead vehicle braking that exceeded the ACC capability) in a practice drive so that participants were primed that the automation could fail in this experiment.

2.1 Participants

Participants were recruited through online forums or posters around campus or nearby residential areas. A total of 32 participants completed the study. In general, the novice drivers were younger than the experienced drivers (Table 1, $F(1,28)=42.94$, $p<.0001$), 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 ($p=.7$). Experienced drivers had a full license for an average of 16.0 years (Range: 9 - 33) with a standard deviation (SD) of 6.8 years, and novice drivers had an average of licensure of 13.8 months (SD: 9.9, Range: 0.5 - 34).

Twenty-six of the participants reported to have never used ACC or LKA systems. One participant reported using the systems several times a week (an experienced driver in the no secondary task condition), and five participants reported using either an ACC or an LKA system less than several times a year (1 experienced driver in the secondary task condition, 2 experienced drivers in the no secondary task condition, 1 novice driver in the secondary task condition, and 1 novice driver in the no secondary task condition).

The experiment took about 2.5 hours. Participants were told that they would be compensated at a rate of $14/hr plus a bonus of up to $8 based on their driving performance (all currency reported in CAD). Participants in the secondary task condition were told that the $8 bonus also depended on their secondary task performance, specifically that they would receive $0.20 for each correct answer and lose $0.40 for each incorrect answer. All participants received the full bonus regardless of their performance. The study received approval from the University of Toronto Research Ethics Board (#35560).

Table 1. Experimental design and participant age (mean, range, and standard deviation (SD))

Experience	Criteria	Secondary Task	Mean Age (Range, SD)
Experienced (n=16)	- Full license in Ontario (or equivalent in Canada or the U.S.) for over 8 years - Drove over 20,000 km in the past 1 year	Yes (n=8)	37.4 (28 - 58, 9.4)
		No (n=8)	39.3 (28 - 52, 9.6)
Novice (n=16)	- G2 license in Ontario (or equivalent in Canada or the U.S.) for less than 3 years - Drove less than 10,000 km in the past 1 year	Yes (n=8)	21.1 (18 - 27, 3.2)
		No (n=8)	21.6 (18 - 24, 1.9)

2.2 Apparatus

The study was conducted in a MiniSim Driving Simulator by NADS (Figure 1a), which is a fixed-base simulator with three 42-inch screens, creating a 130º horizontal and 24º vertical field at a 48-inch viewing distance, with two speakers for stereo sound and a sub-woofer simulating vibration from the road surface. Both ACC and LKA were implemented, operating simultaneously to simulate SAE Level 2 driving automation (SAE On-Road Automated Vehicle Standards Committee, 2018). The ACC maintained a constant cruise speed (which could be adjusted by the participant using the buttons on the steering wheel) for the ego-vehicle and kept a minimum gap time (i.e., distance from back bumper of the lead vehicle to the front bumper of the ego-vehicle divided by the speed of ego-vehicle) to a lead vehicle if a lead vehicle existed and traveled slower than the set speed of the ego-vehicle. The gap time setting was fixed to 2 seconds for all participants, a value that is commonly recommended for safety consideration in highway driving (Wang & Song, 2009). The LKA controlled the steering to keep the vehicle in the center of the lane. Both ACC and LKA could be engaged and disengaged using buttons on the steering wheel. The ACC could also be disengaged by pressing the brake pedal, and the LKA could also be disengaged by turning the steering wheel over 5 degrees. The driving data (e.g., vehicle speed, brake and accelerator pedal positions, and steering wheel angle) was recorded at 60 Hz.

(a) (b)

Figure 1. (a) NADS MiniSim driving simulator; (b) Screenshot of the secondary task

A Surface Pro 2 laptop with a 10.6” touch screen was mounted to the right of the dashboard and presented the secondary task; the screen was off during the no secondary task condition. A Dikablis head-mounted eye-tracking system by Ergoneers was used to record eye movements at 60 Hz. A camera was mounted under the dashboard to record feet movements, and another beside the driver seat to record hand movements.

2.3 Secondary Task

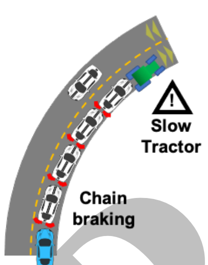
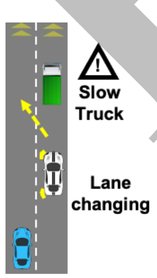
The secondary task that was used in the experiment is a visual-manual task that mimics the operations of in-vehicle infotainment systems (e.g., searching for and selecting songs) (Figure 1b). This task was developed by Donmez et al. (2007) and has been shown across several studies to degrade driving performance (e.g., Chen et al., 2018; Merrikhpour & Donmez, 2017). Participants scrolled through ten 3-word phrases that looked similar to each other and had to find a phrase 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 the screen at a time; participants used up and down arrows to scroll through the 10 phrases. Once participants identified a matching phrase, they had to tap on it and then tap on the submit button. Visual feedback was provided on the correctness of the submission, and then a "start" button appeared on the screen for the participants to initiate a new task. The task was available throughout the whole drive for the secondary task condition, and the participants could decide when to engage in the task and perform it at their own pace. It should be noted that this task is not purely visual-manual. The task is also cognitively demanding to some extent, as participants are required to recall the target phrase and compare it with the ones on the screen. However, it should also be noted that this cognitive component makes the task more realistic, as in-vehicle visual-manual tasks can also be cognitively demanding (e.g., recalling the name of a song while searching for it on the infotainment system display).

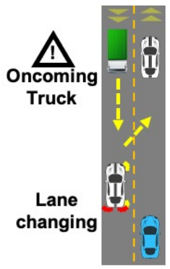
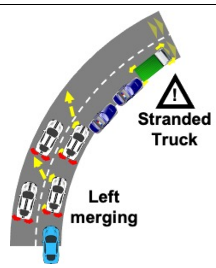
2.4 Driving Task

Participants were told to drive safely, obey speed limits, maintain a comfortable distance from lead vehicles, and use both ACC and LKA when possible. Each participant completed four experimental drives (~5 minutes each), two on a rural road with a speed limit of 80.5 km/h (50 mph), and two on a highway with a speed limit of 96.6 km/h (60 mph). In each drive, participants experienced a unique scenario that enabled anticipation of an upcoming event (see Table 2). The scenarios were adopted from Stahl et al. (2014) and He and Donmez (2018, 2020); He et al. (2021), and all participants experienced the four scenarios in the same order.

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., the onset of the lane changing event in Scenario 2 (see Table 2) would be the directional signal of the following vehicle. Prior to the event onset were anticipatory cues that indicated that an event *may* occur. For example, the diminishing distance between the truck and the following vehicle in Scenario 2 can be considered an anticipatory cue as it indicates that the following vehicle *may* move to the left in front of the ego-vehicle. However, the following vehicle may also slow down to move to the left behind the ego-vehicle. Thus, the intent of the following vehicle is not yet clear before event onset. As noted earlier, the automation was able to successfully navigate all traffic events. The participants were told to disengage the automation or adjust the settings (i.e., change ACC set cruise speed) only when necessary and were not informed of the automation's capability to handle the events in the experiment. In all scenarios, if the driver took no action, the ACC in the ego-vehicle would start to decelerate after event-onset and would safely slow down the vehicle.

Table 2. Description of anticipatory scenarios used in the experiment

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, and braking of lead vehicles (except the one directly ahead) • <u>*Event onset*</u>: brake lights of the lead vehicle directly ahead of the ego-vehicle
	<u>*Lane Changing Event Due to Slow Truck (Scenario 2)*</u> Ego-vehicle traveled at 96.6 km/h in the left lane of a four-lane divided highway. The ego-vehicle approached a truck and a following vehicle on the right lane, which were both traveling at 72.4 km/h (45 mph) initially. 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 approximately 11 seconds (roughly when the participant's vehicle would reach the following vehicle if the participant maintained speed), the following vehicle signaled left for 2 seconds and then pulled out into the left lane, accelerating to 80.5 km/h at a rate of 5 m/s^2, to overtake 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

	*Overtaking Event Due to Oncoming Truck (Scenario 3)* 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 on, 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 oncoming truck, the overtaking vehicle had to cut in front of the ego-vehicle abruptly after signaling right for 2 seconds. • *Anticipatory cues*: the left signal and left lane change of the overtaking vehicle, and the emergence of the oncoming truck • *Event onset*: right signal of the overtaking vehicle
	*Chain Braking Event Due to Stranded Truck (Scenario 4)* 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. • *Anticipatory cues*: the truck and the police vehicles becoming visible • *Event onset*: braking of the vehicle directly ahead

Note: In the sketches, the ego-vehicle is blue; the truck or tractor is green; other vehicles are white except the dark blue police cars in Scenario 4. The dashed yellow arrows show the potential paths of road agents.

2.5 Procedures

Table 3 summarizes experimental procedures.

Table 3. Experimental procedures

Procedure (duration)	**Details**
Consent (~5 min)	Participant eligibility was verified, and written informed consent was obtained from each participant.
Driving task training (~10 min)	Participants were introduced to the manual operation of the vehicle and the automation (i.e., ACC and LKA). They practiced engaging and disengaging the ACC and LKA, and changing the ACC cruise speed in a short drive on an empty straight rural road. Participants were 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 until the participant repeated them correctly.
Secondary task training (~ 5 min)	Participants who were assigned to the secondary task condition were trained on how to complete the secondary task and asked to practise performing the secondary task while not driving.
Practice drive (≥ 10 min)	Participants completed a practice drive on a route similar to the ones in 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. Participants assigned to the secondary task condition were also asked to interact with the secondary task.

Eye-tracker calibration (~ 10 min)	Participants were outfitted with the head-mounted eye-tracking system.
Pre-experiment drive (~ 10 min)	Participants 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 (an intensive braking of the lead vehicle that required drivers to takeover) to prime participants for the possibility of automation failures.
Experimental drives and questionnaires (~ 90 min)	Participants completed the four experimental drives They were told to prioritize driving safety and use both ACC and LKA when possible in all drives, and were found to use ACC and LKA simultaneously for at least 80% of their total driving time. The eye-tracker was re-calibrated before each drive. Participants were allowed a 5-minute rest after each drive, during which they rated the automated driving system they used while considering ACC and LKA as a whole. They rated their trust (i.e., "I can trust the system"), from 1 (not at all) to 7 (extremely), and completed the System Acceptance Questionnaire (Van Der Laan et al., 1997) that measured perceived usefulness and satisfaction, both ranging from -2 (negative) to 2 (positive).
Post-experiment questionnaire (~ 10 min)	At the end of the experiment, participants completed a modified Complacency-Potential Factors Questionnaire (Singh et al., 1993) on a scale of 1 (low) to 5 (high), to assess their trust-related complacency toward commonly encountered automated devices (e.g., ATM); two questions were removed as the relevant tasks are now either obsolete or rarely performed (i.e., searching for books in the library by manually sorting through a card catalogue and taping TV programs manually on a VCR).

2.6 Dependent Variables and Statistical Models

Three categories of data were analyzed: 1) glance behaviors in the interval from 20 s before the first anticipatory cue to the event onset; 2) anticipatory driving behaviors; 3) subjective responses.

We focused on glances to the anticipatory cues and secondary task display, as these types of glances were found to be associated with anticipatory driving (He & Donmez, 2020). Each glance was defined from the gaze starting to move toward an area of interest (AOI) to it starting to move away from the AOI, following ISO 15007-1:2013(E) (International Organization for Standardization, 2014). Glances that fell partially within a data extraction period were handled following the method in Seppelt et al. (2017) and He and Donmez (2020), 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). Two seconds was used as the threshold for long glances based on crash risk research conducted in non-automated driving (Klauer et al., 2006). In order to investigate whether drivers' behavior changed after anticipatory cues became visible (i.e., cue onset), a new independent variable, "cue-onset", was created. The cue-onset variable divided the data into two periods: before-cue-onset (from 20 seconds before cue onset to cue onset) and after-cue-onset (from cue onset to event onset or when the automation was disengaged, whichever occurred first). The length of the before-cue-onset period was always 20 sec, and the average length of the after-cue-onset periods for Scenarios 1, 2, 3, and 4 was 14.1 s, 11.0 s, 12.6 s, and 8.1 s, respectively, with the SD of 2.4, <0.01, 0.9, and 0.6. Table 4 lists the glance measures that are reported in our results section. It should be noted that for the metric, "time until first glance at cues", in Table 4, if a participant did not look at any cues, the time until first glance at cues was considered to be the time from the first cue becoming visible to event onset. 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; the readers are referred to He (2020) for these additional analysis.

Two types of behaviors were considered anticipatory driving behaviors: pre-event actions (i.e., control actions prior to event onset; He & Donmez, 2018; Stahl et al., 2014) and pre-event preparations (i.e., driver preparations to adjust or disengage the automation prior to event onset). We previously used pre-event actions to assess anticipatory driving in non-automated vehicles (He & Donmez, 2018; Stahl et al., 2014). However, pre-event actions may not capture all anticipatory behaviors in automated vehicles, in particular when the situation does not require driver takeover as was the case in our scenarios. Thus, it was important to expand earlier operationalizations of anticipatory driving behaviors to include preparations for a control action (i.e., pre-event preparations). The pre-event actions defined for this study were: 1) pressing the brake pedal to decelerate and disengage the ACC, or pressing the buttons on the steering wheel to disengage the ACC or decrease the set cruise speed of ACC in all scenarios; 2) accelerating by pressing the gas pedal or by pressing the buttons on the steering wheel to increase 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. Pre-event preparations were defined as any of the following identifiable foot or hand movements to prepare for a pre-event action: moving the foot to the gas or brake pedal, moving hands toward the steering wheel, and hovering fingers above any buttons that control the automation.

Table 4. Dependent variables for glance behaviors

Dependent Variable		**Data Extraction Period**
Glances toward cues	- Time until first glance at cues - % of time looking at cues	From the first anticipatory cue becoming visible to event onset
Glances toward secondary task display	- % of time looking at secondary task display - Rates of long glances (> 2 s) at the secondary task display	From *20 s prior to* the first anticipatory cue becoming visible to event onset

** If a participant did not look at any cues, the time until first glance at cues was considered to be the time from the first cue becoming visible to event onset.*

Three raters 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. The raters used eye-tracking videos and videos of participants' feet and hands. 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 (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. 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 these models were accounted for using generalized estimating equations. All other variables were analyzed using repeated measures ANOVAs. All significant ($p<.05$) and marginally significant ($.05<p<.1$) main and interaction effects will be reported in this paper – whether they confirm or disconfirm our hypothesis. The marginal results may reveal patterns in the data that are not conclusive but are potentially informative for future research.

3 Results

3.1 Glance Behaviors

As shown in Table 5 and Figure 2, compared to no secondary task, the secondary task condition was associated with longer time until first glance at cues (mean difference (Δ)=2.7 s, 95% CI: 1.7, 3.7) and lower percentage of time spent looking at cues (Δ=16%, 95% CI: 8, 24). After cue onset, drivers spent a lower percentage of time looking at the secondary task display (Δ=12%, 95% CI: 3, 20) and exhibited a 35% (95% CI: 21, 47) lower rate of long glances to the secondary task display.

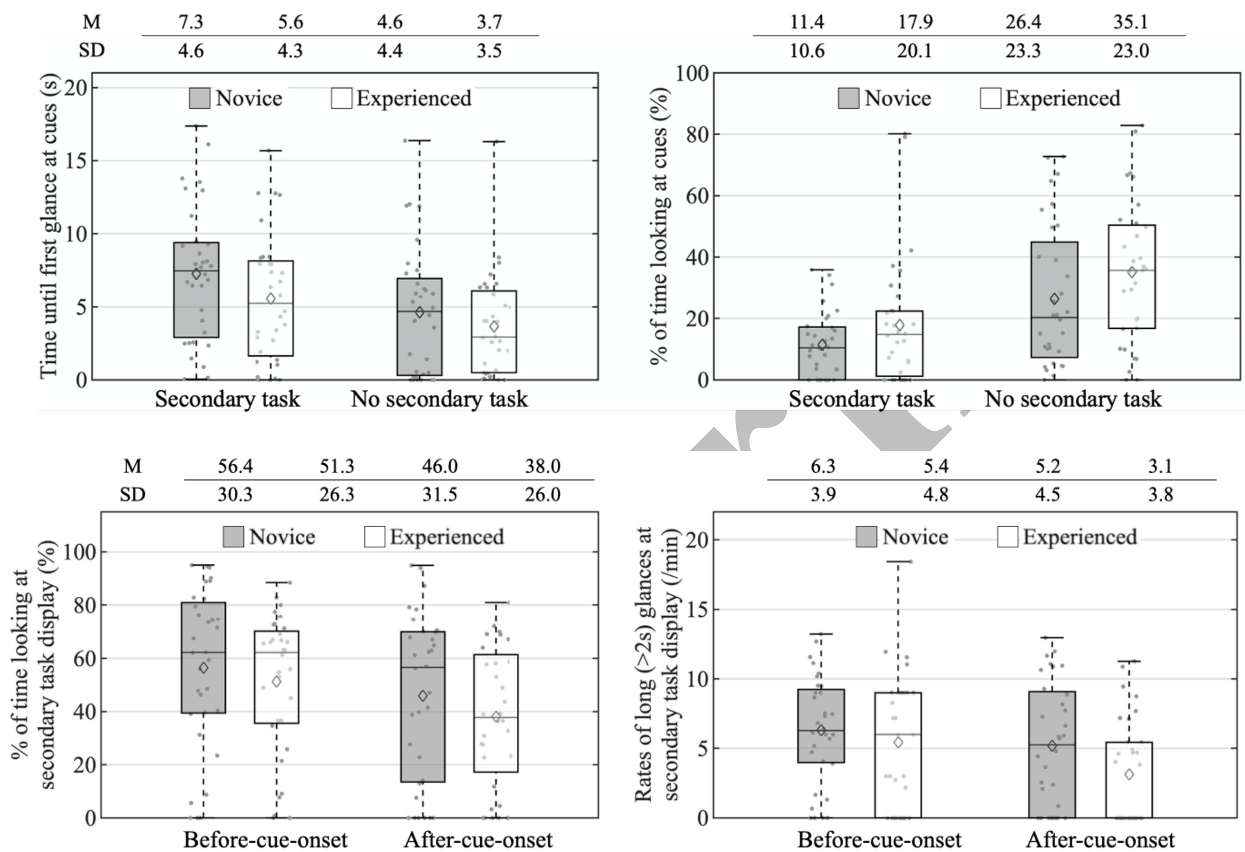


Figure 2. Boxplots of glances at anticipatory cues and the secondary task display. Boxplots present the five-number summary, along with the mean depicted through a hollow diamond. The mean (M) and standard deviation (SD) values are also provided at the top of each plot.

There were two marginally significant effects (see Table 5). A marginally significant effect of experience was observed for percent time looking at cues, with experienced drivers looking at cues for a higher percentage of time (Δ=8%, 95% CI: -1, 16). Further, the interaction of experience and cue-onset was marginally significant for rates of long glances toward the secondary task: for experienced drivers, the rate of long glances to the secondary task was 47% lower (95% CI: 27, 61) after cue onset than before, $\chi^2(1)=15.61$, $p<.0001$, with no significant effect for novice drivers.

3.2 Exhibition of Anticipatory Driving Behaviors

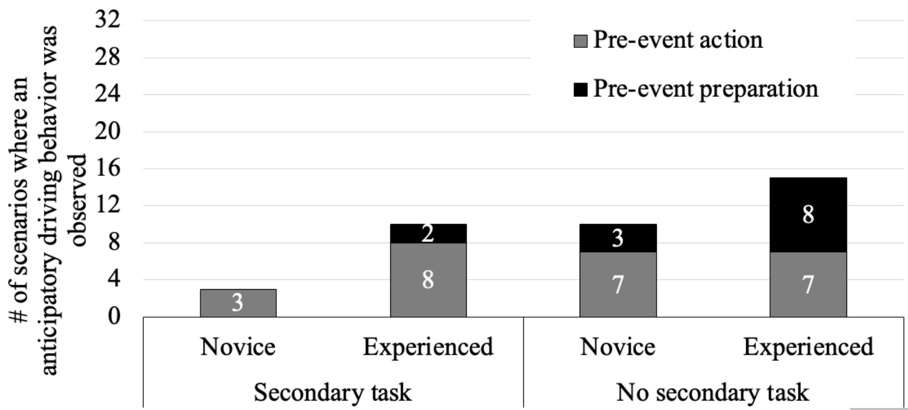
Pre-event actions were more common than pre-event preparations (25 pre-event actions compared to 13 pre-event preparations; Figure 3a). Further, 2 of the 25 pre-event actions (both by experienced drivers, one in the secondary-task and one in the no-secondary-task condition) and 8 of the 13 pre-event preparations were hand movements (seven by experienced drivers, with one in the secondary-task and the rest in the no-secondary task condition; one by a novice driver in the no-secondary-task condition); the rest of the pre-event actions and pre-event preparations were foot movements. Twenty-one participants exhibited at least one anticipatory driving behavior across the four scenarios; 11 participants exhibited no anticipatory driving behaviors (Figure 3b).

Statistical model results are shown in Table 5. Compared with 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 2.92, 95% CI: 1.16, 7.32, and the presence of the secondary task decreased the likelihood of anticipatory driving behaviors, OR=0.34, 95% CI: 0.14, 0.86. Given that prior anticipatory driving research for non-automated vehicles (He & Donmez, 2020) focused only on pre-event actions, we conducted additional analysis to focus on the exhibition of just this type of anticipatory behavior for comparison purposes; no significant effects were found. When we analyzed the scenarios where an anticipatory behavior was observed with regards to whether the behavior was a pre-event action or pre-event preparation, we found that drivers in the secondary task condition were more likely to exhibit pre-event actions over pre-event preparation, OR=5.49, 95% CI: 1.39, 21.71. The experience and secondary task interaction was not estimable for type of anticipatory driving behavior because there were no instances of pre-event preparation for novice drivers in the secondary task condition (see Figure 3a).

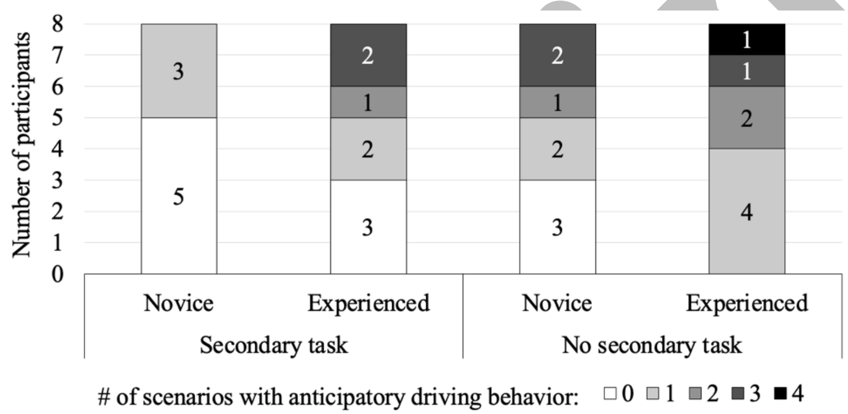
Table 5. Statistical results for glance and anticipatory driving behavior measures

Dependent Variables		Experience	Secondary task	Experience × Secondary task	Cue-onset	Experience × Cue-onset
		Independent Variables				
Glances toward cues	Time until first glance	F(1,28)=2.2 p=.15 ω_p^2=0.02	F(1,28)=6.39 p=.02** ω_p^2=0.07	F(1,28)=0.16 p=.69 ω_p^2=-0.01	- - -	- - -
	% of time looking	F(1,28)=3.57 p=.07* $\omega_p^2=0.05$	F(1,28)=16.28 p=.0004** $\omega_p^2=0.15$	F(1,28)=0.08 p=.79 $\omega_p^2=-0.01$	- - -	- - -
Glances toward secondary task display	% of time looking	F(1,14)=0.52 p=.48 $\omega_p^2=0.01$	- - -	- - -	F(1,110)=7.62 p=.007** $\omega_p^2=0.05$	F(1,110)=0.10 p=.75 $\omega_p^2=-0.01$
	Rate of long (>2s) glances	χ^2(1)=1.59 p=.21	- -	- -	χ^2(1)=17.68 p<.0001**	χ^2(1)=3.67 p=.055*
Anticipatory driving behaviors	Anticipatory driving behavior *(yes vs. no)*	χ^2(1)=5.22 p=.02**	χ^2(1)=5.22 p=.02**	χ^2(1)=0.76 p=.38	- -	- -
	Pre-event action *(yes vs. no)*	χ^2(1)=1.20 p=.27	χ^2(1)=0.59 p=.44	χ^2(1)=1.20 p=.27	- -	- -
	Type of anticipatory behavior *(pre-event action vs. preparation)*	χ^2(1)=2.26 p=.13	χ^2(1)=5.88 p=.02**	-	-	-

*Note: ** marks significant results (p<.05) and * marks marginally statistically significant results (.05<p<.1). Effect sizes for ANOVAs are reported through partial omega squared (ω_p^2) (Keren & Lewis, 1979).*



(a)



(b)

Figure 3. (a) Visualization of anticipatory driving behaviors at the scenario level: the number of scenarios where an anticipatory driving behavior was observed. The number of scenarios under each experimental condition is 32 with 4 scenarios per participant and 8 participants within each condition, representing the maximum value for the y-axis. Pre-event preparation counts are based on scenarios with only a pre-event preparation (no pre-event action); pre-event action counts include any scenario with a pre-event action, including those that were preceded by pre-event preparation. (b) Visualization of anticipatory driving behaviors at the participant level: the number of participants who displayed anticipatory driving behaviors (pre-event action or preparation) in 0, 1, 2, 3 or 4 scenarios within each experimental condition. The

number of scenarios is indicated using a color gradient with darker shades corresponding to more scenarios with anticipatory driving behaviors.

To visualize the potential influence of experimental condition on drivers' behaviors, the average timing of participants' first responses is presented in Figure 4. Some participants exhibited no anticipatory driving behaviors (pre-event actions or pre-event preparations) but responded after event onset. Thus, in addition to the timing of pre-event responses, the timing of post-event responses is also provided in the figure: post-event preparations (driver preparations to adjust or disengage the automation after event onset) and post-event actions (control actions after event onset). Statistical models were not built due to sample size limitations, but inspection of Figure 4 reveals that, in general, experienced drivers exhibited pre-event preparations earlier compared to novice drivers, indicating that the experienced drivers may have been quicker in understanding the anticipatory scenarios compared to novice drivers. Figure 4 also indicates that experienced drivers did not necessarily disengage the automation (i.e., exhibit pre-event actions) earlier compared to novices, potentially because experienced drivers waited to see if the situation would develop as anticipated.

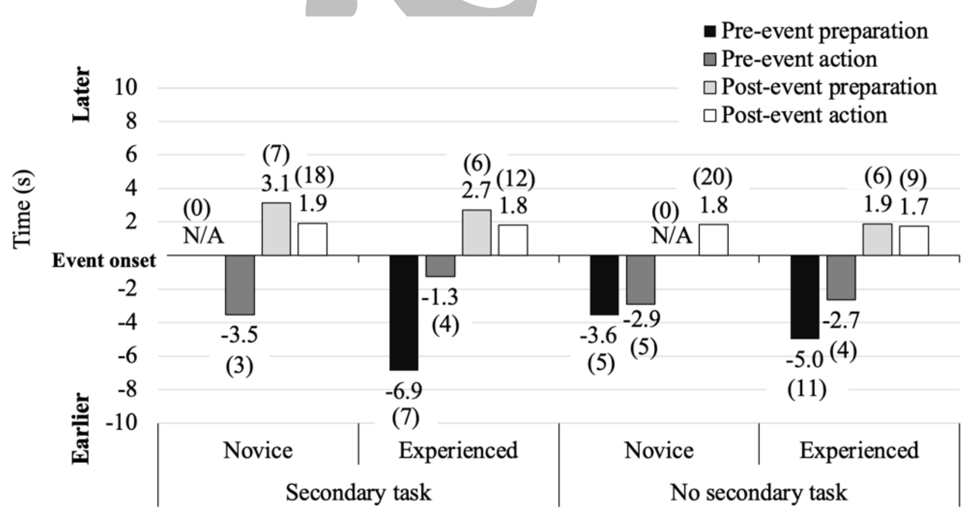


Figure 4. Average timing of participants' responses relative to event onset in different experimental conditions. If participants exhibited multiple responses (e.g., pre-event preparation followed by post-event

action), the timing of the first response was used (pre-event preparation in the example). On the y-axis, event onset corresponds to 0. Negative values represent responses before event onset and positive values represent responses after event onset. Numbers in brackets represent the number of scenarios where each behavior was exhibited as the first response (maximum is 32: 4 scenarios*8 participants). N/A: timing information not available as there are no responses of the corresponding type.

3.3 Relationship between Glances and Anticipatory Driving Behaviors

To further understand the relationship between glance behaviors and anticipatory driving behaviors, we compared glance metrics between scenarios where anticipatory driving behaviors were observed and where no anticipatory driving behaviors were observed. Admittedly, this analysis may be underpowered given that anticipatory driving behaviors were infrequent under certain conditions (see Figure 3).

We observed an interaction effect between the exhibition of anticipatory driving behaviors and cue-onset for percent of time spent looking at the secondary task display, F(1,109)=4.13, p=.04, ω_p^2=0.02 (Figure 5a). In scenarios where an anticipatory driving behavior was observed, percent of time looking at the secondary task display was 27% lower (95% CI: 10, 44) after cue onset, $F(1,109)$=3.17, p=.002; there was no significant difference in scenarios where no anticipatory driving behavior was observed.

An interaction between exhibition of anticipatory driving behavior and cue-onset was also observed for rates of long glances toward the secondary task display, $\chi^2(1)$=7.24, p=.007 (Figure 5b). Overall, drivers reduced rates of long glances toward the secondary task after cue onset. However, this effect was larger for scenarios where anticipatory driving behaviors were observed (Δ=-60%, 95% CI: -75, -35, $\chi^2(1)$=14.0, p=.0002) compared to scenarios where no anticipatory driving behavior was observed (Δ=-26%, 95% CI: -40, -8, $\chi^2(1)$=7.25, p=.007).

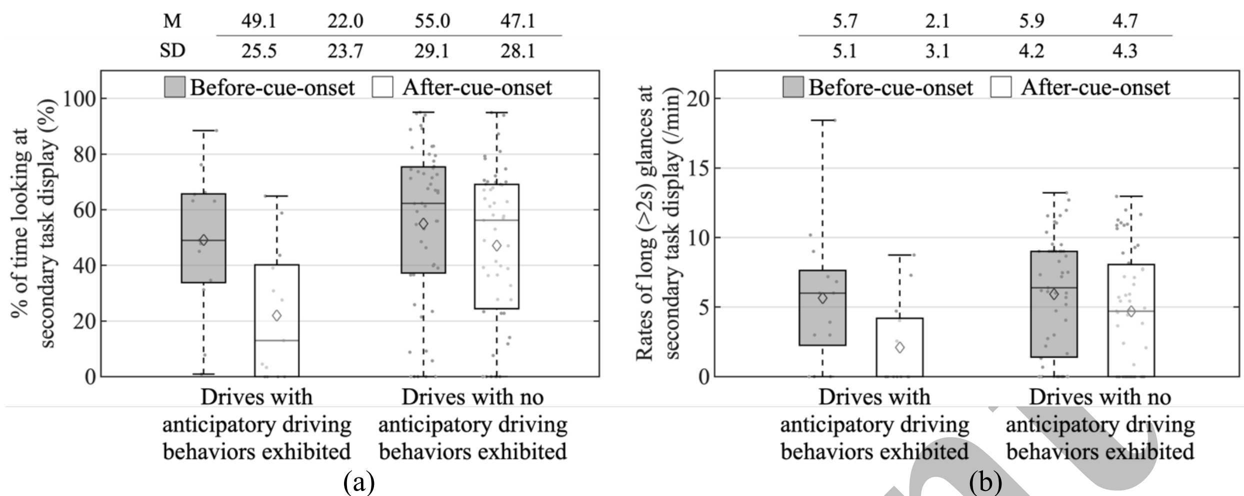


Figure 5. Boxplots of glances at the secondary task display for drives with and without anticipatory driving behaviors, by cue-onset. Boxplots present the five-number summary, along with the mean depicted through a hollow diamond. The mean (M) and standard deviation (SD) values are also provided at the top of each plot.

3.4 Subjective Ratings

Overall, experienced drivers reported lower trust-related complacency toward commonly encountered automated devices compared with novice drivers, $F(1,28)=8.33$, $p=.007$, $\Delta=-1.00$, 95% CI: -1.71, 0.29, $\omega_p^2=0.19$. Drivers rated the automated driving system as less useful in drives where anticipatory behaviors were observed, $F(1,95)=8.25$, $p=.005$, $\Delta=0.14$, 95% CI: 0.04, 0.24, $\omega_p^2=0.05$. These were the only significant findings for subjective ratings in this experiment.

4 Discussion

Similar to what has been observed for non-automated vehicles (He & Donmez, 2018, 2020), in automated vehicles, the presence of a secondary task impaired driver attention to anticipatory cues indicating upcoming traffic events and impeded anticipatory driving behaviors. Drivers in the secondary task condition were more likely to exhibit pre-event actions compared to pre-event preparations only. It is possible that due to their delayed first glance at the cues when the secondary task was present, drivers did not have as much time to assess the situation. As the secondary task claimed more of drivers' attentional resources, they may have become more conservative in their choice of action.

Overall, drivers in the secondary task condition reduced their visual attention toward the secondary task after cue onset; and this effect was more pronounced in drives with anticipatory driving behaviors. A larger reduction in rates of long glances toward the secondary task display after cue onset was observed in drives with anticipatory behaviors compared to drives without anticipatory driving behaviors. Further, a significant reduction in the percent of time looking at the secondary task display after cue onset was observed in drives with anticipatory driving behaviors but not in drives without anticipatory driving behaviors. These results suggest that anticipation in automated vehicles, with the presence of a secondary task, may be influenced by drivers' ability to manage their distraction engagement. It may also be possible that anticipatory drivers may be better at adjusting their attention allocation as they are more aware of the potential development of traffic.

Driving experience, as opposed to what has been observed in non-automated vehicles (He & Donmez, 2018, 2020; Stahl et al., 2019), was not observed to enhance driver attention to anticipatory cues in automated vehicles, except for a marginally significant effect (percent time looking at cues was marginally significantly higher for experienced drivers). The effect of experience on visual attention to cues in non-automated vehicles may be due to the differences in manual control skill. Novice drivers are less skilled in handling non-automated vehicles compared to experienced drivers (Bjørnskau & Sagberg, 2005) and therefore may focus more of their cognitive resources on executing the manual control of the vehicle. Manually controlling the vehicle is less effortful for experienced drivers, giving them more spare attentional capacity to attend to anticipatory cues. In automated vehicles, however, as automation frees up drivers from manually controlling the vehicle, both novice and experienced drivers may have a similar level of spare attentional capacity to monitor the road.

While experienced and novice drivers attended to the anticipatory cues to a similar extent, experienced drivers may still be better at interpreting these cues to anticipate upcoming traffic events as we found experienced drivers to be more likely to exhibit anticipatory driving behaviors. Jackson et al.

(2009) similarly suggested that experienced drivers are better able to interpret cues to predict road hazards. In the current study, a marginally statistically significant effect was found with experienced drivers reducing their rates of long glances to the secondary task display after the appearance of anticipatory cues while novices did not. Further, visual inspection of the data indicates that when the average timing of pre-event preparations is compared across drivers who exhibited pre-event preparations, experienced drivers' response was earlier than novices. Thus, compared to novices, experienced drivers may have been better at anticipating the upcoming events based on the cues and adjusting their attention allocation accordingly. However, a larger sample size is needed to further test these marginally significant effects, which are smaller in effect size.

Trust in automation may also have influenced experienced drivers' anticipatory behaviors. We did not find a relationship between drivers' trust in the automated driving systems and whether they exhibited anticipatory driving behaviors. However, considering that drivers in our experiment had limited experience with the automated driving systems both in the experiment and in their daily life, their initial trust in and reliance on the automated driving systems might be based on their attitudes toward automation in general (Lee & Kolodge, 2020; Lee & See, 2004). Experienced drivers reported lower trust-related complacency toward commonly encountered automated devices compared to novices, which might in part explain their higher likelihood of taking over or preparing to take over from the automation prior to an event. Further, as mentioned previously, experienced drivers made fewer long glances to the secondary task after anticipatory cues appeared, a result that approached significance, suggesting that their lower trust may have led to lower reliance on automation before traffic events; lower secondary task engagement has been used as an indicator of lower reliance on driving automation (Körber et al., 2018). However, research with larger samples is needed to further explore the relationship between trust, anticipation, and reliance in automated vehicles.

In summary, the findings from this study provide new insights on the role of driving experience and secondary task engagement in automated vehicles. Previous research showed that driving experience impacts drivers' behaviors at the operational level in automated vehicles (e.g., speed control; Young &

Stanton, 2007). Our research extends this finding by investigating the influence of driving experience and the presence of a secondary task on drivers' behaviors at the tactical level (i.e., the anticipation of upcoming traffic events). Engagement in a secondary task was found to impede anticipation, which can in turn lead to safety degradations. Adaptive interfaces that limit the availability of secondary tasks based on an estimation of driving demands may help improve driving safety in automated vehicles (DeGuzman et al., in press). For example, connected vehicle technology can be leveraged to gain information about traffic situations ahead that may require driver action. If such a situation is detected, the system can lock in-vehicle interfaces to reduce distraction. Driving experience was found to facilitate anticipation, potentially because experienced drivers are better able to interpret cues in the environment that indicate upcoming traffic events. Thus, training or in-vehicle interfaces that aim to improve drivers' ability to identify and interpret cues in the environment may improve driving safety in automated vehicles by facilitating anticipation. For example, similar to what has been proposed in non-automated vehicles (e.g., Stahl et al., 2016; Unverricht et al., 2018), interfaces for automated vehicles could direct drivers' attention to potential hazards and/or anticipatory cues (He et al., 2021).

It is important to reiterate that in all of our scenarios, the automation could handle the event without intervention from the driver. Thus, it is possible that some drivers could have anticipated the upcoming events but chose not to disengage the automation or prepare to take an action. These drivers may be those who have higher trust in and reliance on the automation. Future research can try to identify anticipatory but non-reactive drivers by incorporating further measures (e.g., post-experiment questionnaires regarding understanding of the scenarios). Further, we used a limited range of scenarios, and in these scenarios a change of speed was always an appropriate response, whereas steering was appropriate only in one. Thus, it is not surprising that most of the anticipatory driving behaviors were foot movements, as drivers are likely more inclined to accelerate or decelerate using the gas and brake pedals than changing the automation setting via the steering wheel buttons. Future research may explore a wider variety of scenarios, for example, scenarios where swerving or changing lanes would be a better choice compared to a change of speed, to assess whether similar results are found in scenarios where hand movements are preferred. Each participant experienced one automation failure in the practise drive in order to prime them for automation failures. In reality, drivers would have different levels of exposure to automation failures, which may lead to varied responses. Future research should consider varying the amount and type of exposure to automation failures (e.g., firsthand experience or verbal instruction), as how failures are experienced can determine drivers' trust and reliance on the automation (Beggiato & Krems, 2013). Lastly, in the current experiment, the automation could handle potential traffic conflicts without driver intervention. Driver behaviors might differ in more critical situations where driver intervention is necessary to avoid a collision (Eriksson & Stanton, 2017), and thus future studies need to investigate anticipatory driving behaviors in such critical situations.

Key Points

- In a simulated automated vehicle, the presence of a visual-manual secondary task was associated with a lower percentage of time looking at anticipatory cues that indicated an upcoming traffic event and a longer time to first glance at these cues, as well as a lower likelihood of exhibiting anticipatory driving behaviors.
- Experienced drivers exhibited more anticipatory driving behaviors than novice drivers; however, they were not found to allocate more visual attention toward anticipatory cues suggesting that they may have been more effective in interpreting these cues.
- In scenarios where an anticipatory driving behavior was observed, drivers spent a lower percent of time looking at the secondary task compared to scenarios where no anticipatory driving behaviors were observed. There appears to be a relation between reliance on automation and anticipatory driving.

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