Topic: Surface Transportation

The Influence of Visual-Manual Distractions on Anticipatory Driving

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Abstract

Objective: Investigate how anticipatory driving is influenced by distraction. ***Background:*** The anticipation of future events in traffic can allow potential gains in recognition and response times. Anticipatory actions (i.e., control actions in preparation for potential traffic changes) have been found to be more prevalent among experienced drivers in simulator studies when driving was the sole task. Despite the prevalence of visual-manual distractions and their negative effects on road safety, their influence on anticipatory driving has not yet been investigated beyond hazard anticipation. ***Methods:*** A simulator experiment was conducted with 16 experienced and 16 novice drivers. Half of the participants were provided with a self-paced visual-manual secondary task presented on a dashboard display. ***Results:*** More anticipatory actions were observed among experienced drivers; experienced drivers also exhibited more efficient visual scanning behaviors as indicated by higher glance rates toward and percent times looking at cues that facilitate the anticipation of upcoming events. Regardless of experience, those experiencing the secondary task displayed reduced anticipatory actions and paid less attention toward anticipatory cues. However, experienced drivers had lower odds of exhibiting long glances toward the secondary task compared to novices. Further, the addition of glance duration on anticipatory cues increased the accuracy of a model predicting anticipatory actions based on on-road glance durations. ***Conclusion:*** The results provide additional evidence to existing literature supporting the role of driving experience and distraction engagement in anticipatory driving. ***Application:*** These findings can guide the design of in-vehicle systems, and guide training programs to support anticipatory driving.

Keywords: Driver distraction, Anticipation, Driving simulators, Driver behavior, Experience

Precis: In a simulator, we investigated the effect of a visual-manual secondary task on anticipatory driving for both novice and experienced drivers. The secondary task impeded anticipatory driving for both groups, but experienced drivers showed more efficient visual attention allocation behaviors even when distracted to a similar extent.

Introduction

Crash risk is known to decrease with the accumulation of mileage (Mayhew, Simpson, & Pak, 2003). With experience, drivers become better at vehicle handling (Bjørnskau & Sagberg, 2005) and also at visually scanning the driving environment. For example, experienced drivers' fixations cover a wider area (Mourant & Rockwell, 1972); they vary the width of their horizontal scanning to accommodate differing complexities in the roadway whereas novice drivers do not (Crundall & Underwood, 1998); they fixate more on risky features of a scenario than novices (Lehtonen et al., 2014; Pradhan et al., 2005); when engaged in visual-manual secondary tasks, experienced drivers have fewer risky off-road glances (i.e., longer than 3 seconds) than novices (Wikman, Nieminen, & Summala, 1998); and they commit fewer driving infractions when engaged in a hands-free cell phone task (Kass, Cole, & Stanny, 2007). Experienced drivers are also known to be better at perceiving hazards on the road (Sagberg & Bjørnskau, 2006). Better hazard perception might in part be attributed to drivers' improved capability to anticipate how traffic can evolve in the future (Stahl, Donmez, & Jamieson, 2014, 2016, 2019).

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). A number of hazard perception studies have shown that hazard anticipation is more prevalent among experienced drivers than they are among novices (e.g., Crundall et al., 2012; Lee et al., 2008), and that experienced drivers better scan areas that indicate potential hazards (e.g., Muttart, Fisher, & Pollatsek, 2014). These studies provided an advancement over earlier hazard perception studies where standard hazard perception tests were used to record reaction times to a sudden onset hazard (Chapman & Underwood, 1998), a situation that does not enable anticipation. Lee et al. (2008), Crundall et al. (2012), and Muttart et al. (2014) utilized 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. 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, were still surprise events and 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 the 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, would better assess the high-level cognitive competence of anticipation in driving.

In Stahl et al. (2014, 2016, 2019), we were the first to utilize such complex scenarios to investigate anticipation beyond the perspective of hazard anticipation. In one scenario, for example, the participant driving on the left lane of a two-lane highway approached another vehicle on the right lane closing on a slow-moving truck. The anticipatory driver could speed up or slow down before the vehicle on the right started to change lanes. Thus, in addition to simulating the dynamics between multiple traffic agents, we also allowed for a variety of anticipatory actions (i.e., proactive control actions in anticipation of a probable traffic event) depending on the driver goals (e.g., increasing safety margins, minimizing effort, or reducing travel times). A conflict did not need to occur if the driver demonstrated avoidance responses. Across two separate simulator studies, we found experienced drivers to exhibit more anticipatory actions than novices (Stahl et al., 2014, 2016), and drivers who exhibited anticipatory actions to have more frequent and longer glances toward relevant cues than those who did not exhibit any (Stahl et al., 2019). Further, we showed that novice drivers can be supported to exhibit more anticipatory actions through the use of in-vehicle information displays (Stahl et al., 2016).

Despite the above efforts to extend the understanding of anticipatory driving (Stahl et al., 2014, 2016, 2019), there is still little understanding of anticipatory driving when driving is not the sole task of the driver. Given that anticipation depends on perception, it is expected to degrade with activities secondary to driving that compete for the same perceptual resources. There have been a limited number of studies that investigated the effects of cognitive distraction on anticipation; these studies focused mainly on auditory-vocal secondary tasks. Mühl et al. (2019) found through video simulations that increased cognitive load degraded experienced drivers' ability to anticipate the action of another vehicle. Horberry et al. (2006) found that drivers had higher speeds approaching a behavioral prediction hazard (i.e., pedestrian crossing the road) with a hands-free cell-phone task compared to no task; age also had an effect with drivers over 60 years old having lower approach speeds than drivers younger than 25. Further, Biondi et al. (2015) found that with increased cognitive load, experienced drivers exhibited more failures to visually scan both their left and right at an intersection; although the authors titled their paper to indicate that they captured "anticipatory glances", we would argue that these glance analyses do not qualify as studying anticipation given that specific elements on the roadway were not considered but the authors looked at two broad areas (i.e., left and right) that need to be scanned at an intersection in general. Although limited, these three studies indicate that cognitive distraction can potentially impair anticipation.

Driving however is a mainly visual-manual task and distractions that require visual perception and manual action overlap the most with the driving task and hence are the most detrimental to safety (Dingus et al., 2016). 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. Drivers are known to reduce their secondary task engagement based on roadway demands (Schömig & Metz, 2013). However, the obstruction task in Borowsky et al. (2015) was not self-paced, and hence created a contrived setting by removing the drivers' ability to moderate their distraction engagement based on their anticipation of a hazard. Lee et al. (2008) and Pradhan et al. (2011) investigated self-paced visual-manual tasks and environmental prediction hazards and found trends in their data suggesting that novice drivers are worse than their experienced parent drivers in hazard perception while distracted, but exhibit 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 affects hazard anticipation for either group. Further, both studies focused on environmental prediction hazards only. Horberry et al. (2006) found that drivers had higher speeds approaching a pedestrian-crossing-the-road hazard with a visual-manual in-car task compared to no task. However, their hazard event was more about detection than it was about anticipation; that is, there were no additional cues other than the pedestrian itself that could enable the anticipation of the pedestrian's behaviour. 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 anticipation. It is expected that they would hinder anticipatory driving, but experienced drivers' anticipatory behaviors would be affected less compared to novices.

This paper presents the results of a driving simulator study investigating the influence of visual-manual distractions on anticipatory driving behaviors of both novice and experienced drivers, beyond just hazard anticipation. 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. We analyzed drivers' anticipatory actions across multiple scenarios, their engagement with the secondary task, and their glances toward the traffic cues that are relevant to how traffic may develop in the future (i.e., anticipatory cues). Some of the earlier results from the experiment reported in this paper were published in a conference article (He & Donmez, 2018). In this current paper, we analysed anticipatory actions at the scenario level whereas the previous paper looked at these actions at the subject level in an aggregated manner. Further, all glance data were re-analysed using the ISO 15007-1:2014(E) standard (International Organization for Standardization, 2014). More importantly, to quantify attention allocation in more detail, we conducted additional analysis on glance behaviors by considering the temporal development of the traffic scenarios (by looking at time series of glance behaviors and comparing driver behaviors before and after the onset of anticipatory cues), and we investigated the relation between anticipatory actions and glance metrics. Part of the methods was also presented in He and Donmez (2018), in particular, scenario descriptions.

Methods

The experiment had a 2 × 2 between-subjects design, with 4 male and 4 female participants in each of the four conditions, resulting in 32 participants total. 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). Novice drivers obtained their first learner's license (e.g., G2 license in Ontario, Canada) less than 3 years prior and had driven less than 10,000 km in the past year. Experienced drivers had a full driver's license (e.g., G license in Ontario, Canada) for at least 8 years and had driven more than 20,000 km in the past year. Each participant completed four scenarios in the simulator, with each scenario involving several traffic cues designed to allow the anticipation of an event.

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 above. Our sample size was 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, $t(14)=1.19$, $p=.26$. The study received approval from the University of Toronto Research Ethics Board (#34679). Informed consent was obtained from each participant. Regardless of performance, all participants received C$50. However, participants were told that they could receive a bonus of up to $8 based on their performance: for the no secondary task condition, this bonus was tied to driving performance only; for the secondary task condition, it was tied to both driving and secondary task performances. Participants in the secondary task condition were further told that they would receive $0.20 and lose $0.40 for each correct/incorrect answer in the secondary task.

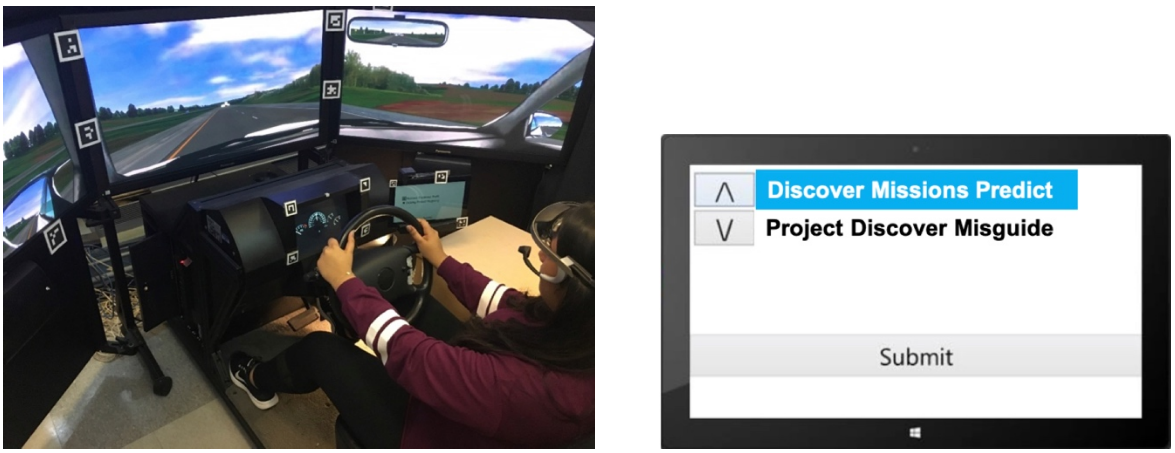
Apparatus

The experiment was conducted on a fixed-base MiniSim Driving Simulator by NADS (Figure 1a). The simulator has three 42-inch screens creating a 130° horizontal and 24° vertical field of road view at a 48-inch viewing distance. The secondary task was displayed on a touch-screen Surface Pro 2 (screen size of 235 mm × 132 mm) mounted to the right of the dashboard. A Dikablis head-mounted eye tracking system by Ergoneers was used to record gaze position at 60Hz. The device overlays gaze position (as crosshairs, see Figure 3) on video captured by its front-facing camera (resolution of 1920 × 1080 at 30 fps). This video is available to the experimenter during data collection, and enables the confirmation of satisfactory calibration: the experimenter asks participants to fixate their gaze on different points on the screens and confirms through recorded video that the crosshairs fall on the point the participant is asked to fixate on. The manufacturer reported glance direction accuracy to vary between 0.1° to 0.3° of visual angle (translating to 2 mm to 6 mm on the middle simulator screen at a viewing distance of 48 inches). Another camera mounted below the dashboard was used to record pedal movements.

Secondary Task

The secondary task was a self-paced visual-manual task developed by Donmez, Boyle and Lee (2007) and has been shown to degrade driving performance in various simulator studies (Chen, Hoekstra-Atwood, & Donmez, 2018; Merrikhpour & Donmez, 2017). It mimics in-vehicle infotainment system tasks, such as searching and selection a song or a radio station. The participants are asked to scroll through strings of three words to find a string that has either “Discover” as the first word, or “Project” as the middle word, or “Missions” as the last word.

Two strings (of three words) are displayed at one time and there is one correct answer in a list of 10 strings. This task was available throughout the drive for secondary task conditions, and participants decided when to start the task and did so by hitting a start button. They pressed a submit button to indicate their selection and received visual feedback on whether it was correct or not. Then, the start button became available again for the participants to initiate another interaction.

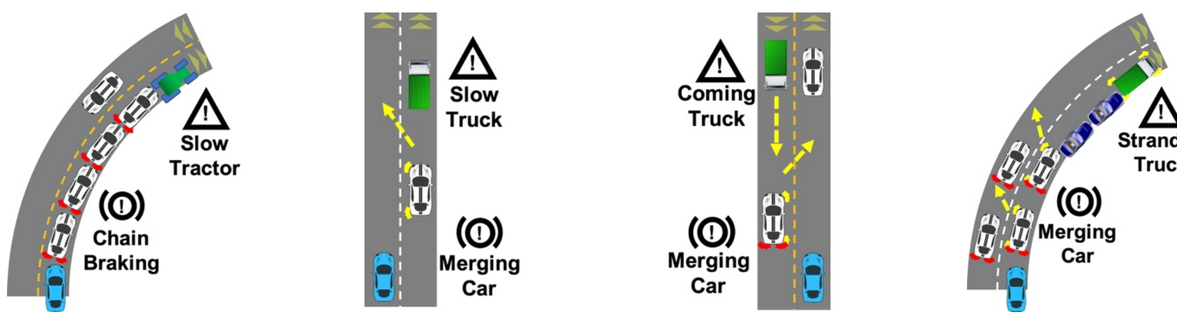


(a) (b)

Figure 1. (a) MiniSim driving simulator with a secondary task display mounted to the right of the dashboard; (b) Screenshot of secondary task.

Driving 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 Figure 2. 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 we could not fully counterbalance the scenario order across the number of participants we had: 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). Although detailed scenario descriptions were provided in He and Donmez (2018), we repeat them below for the readers' convenience. Further, we provide example images of participants attending to the anticipatory cues in Figure 3.



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

Figure 2. Sketches of the four anticipatory scenarios and relative positions of road agents. The blue vehicle at the bottom of each image represents the participant vehicle; the green vehicles at the top are trucks or tractors; other vehicles are white except the dark blue police vehicles in Scenario 4. The arrows indicate potential future paths; double arrows indicate lane direction. The broken yellow lines separate lanes with opposing traffic, the broken white lines separate lanes with traffic in the same direction. (a) Scenario 1: chain-braking due to a slow-moving tractor; (b) Scenario 2: vehicle merging to participant-lane due to slow-moving truck on highway; (c) Scenario 3: vehicle behind cutting in front; (d) Scenario 4: stranded truck on highway shoulder.

Scenario 1. The participant was instructed to follow a chain of vehicles on a two-lane rural road with moderate oncoming traffic. The chain consisted of four passenger cars traveling at 80.5 km/h (50 mph). Because of a green tractor traveling at 40.2 km/h (25 mph) in front, the vehicles ahead started to brake consecutively on a curve. The front-most lead vehicle started to brake when within 87.4 m of the tractor, with a deceleration of around 8 m/s^2 for 3 seconds. The following vehicles braked in succession, with the deceleration decided by the simulator. The first anticipatory cue was the tractor becoming visible (Figure 3a); others were the brake lights of each consecutive vehicle in the chain (except the one directly ahead of the participant). As all vehicles had to slow down, the visible deceleration and diminishing headway distances between the vehicles were also considered to be anticipatory cues. The event onset was defined as the brake lights of the vehicle directly ahead of the participant's vehicle turning on.

Scenario 2. The participant was instructed to maintain 96.6 km/h on the left lane while driving on a four-lane divided highway. A truck was travelling at 72.4 km/h (45 mph) and was followed by a passenger vehicle driving at the same speed. Both vehicles were ahead of the participant vehicle. Once the participant vehicle reached within 244 m of the truck, the truck slowed down to 64.7 km/h (40 mph) and the following vehicle accelerated to 75.6 km/h (47 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. The changes in speed and the diminishing headway distance between the truck and the following vehicle (Figure 3b) were considered to be anticipatory cues to the event. The event onset was defined as the turn signal onset of the following vehicle.

Scenario 3. The participant was instructed to follow a lead vehicle on a rural road. Upon reaching a straight section, a vehicle directly behind signaled left for 2 seconds with high beams on, pulled into the opposite lane, and accelerated to reach a speed 7.2 km/h (4.5 mph) above the participant's vehicle speed to overtake it. Because an oncoming truck appeared in the opposing lane, the overtaking vehicle had to cut in front of the participant vehicle abruptly, after signaling right for 2 seconds. The first anticipatory cue was the left signal onset of the overtaking vehicle, and was followed by the overtaking vehicle's lane change to the opposing lane (Figure 3c). These cues were visible to the participants in rear- and left-side mirrors. Another anticipatory cue was the appearance of the oncoming truck in the opposing lane. The event onset was defined as the right signal onset of the overtaking vehicle.

Scenario 4. The participant was instructed to drive on the right lane of a four-lane divided highway, following a vehicle. A truck stranded on the highway shoulder and two police cars parked behind the truck with flashing lights on appeared on a curve. The lead vehicle in front of the participant started signaling left for 2 seconds and started braking at the same time with a deceleration rate of 5 m/s^2. The cars on the left also braked to make room for merging vehicles with deceleration rates of 5 m/s^2. The anticipatory cue was the truck and the police vehicles becoming visible to the participants (Figure 3d). The event onset was defined as the left signal and brake light onset (happened at the same time) of the lead vehicle.

(a)

(b)

(c) (d)

Figure 3. Images from eye-tracking videos for the four scenarios. In each image, the participant's gaze (indicated by crosshairs) is on an anticipatory cue. (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.

Procedures

Participants completed an acclimation drive on a route similar to the routes used in the experiment in terms of traffic density and road type. 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. Participants then completed the four experimental drives. Eye-tracker was calibrated in the beginning of the experiment and was re-calibrated before each drive. After each drive, participants completed questionnaires on workload and perceived risk, which are not reported in this paper but were reported in He and Donmez (2019).

Dependent Variables of Anticipation and Secondary Task Engagement

Exhibition of a Pre-event Action. Three raters, 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 no clear pre-event action could be identified. 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 merging left (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 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 rater before they discussed their categorizations, Fleiss' κ=0.6 (Fleiss, 1971). Conflicts were then resolved through discussions.

Glance Behaviors. Glance metrics (Table 1) 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 towards 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 1. Glance behavior metrics.

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 recent work, our group found in the simulator that experienced drivers have more and longer glances on anticipatory cues compared to novices (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 1 presents relevant findings mainly from naturalistic driving studies, connecting our 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 1 focused on on-path vs. off-path glances. However, eye-tracking data from our study provides rich information regarding gaze location and hence we 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. Our metrics on anticipatory cues 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.

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 post-cue-onset. Before-cue-onset period corresponded to the period from 20 seconds prior to cue onset to cue onset, the post-cue-onset period corresponded to the period from cue onset to event onset. Not all independent variables were applicable to every model (e.g., 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 post-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).

Results

Exhibition of a Pre-event Action

The number of scenarios where a pre-event action was observed (Figure 4) 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. These findings were in line with our earlier analysis reported in He and Donmez (2018), which investigated anticipatory actions at the driver level rather than scenario level.

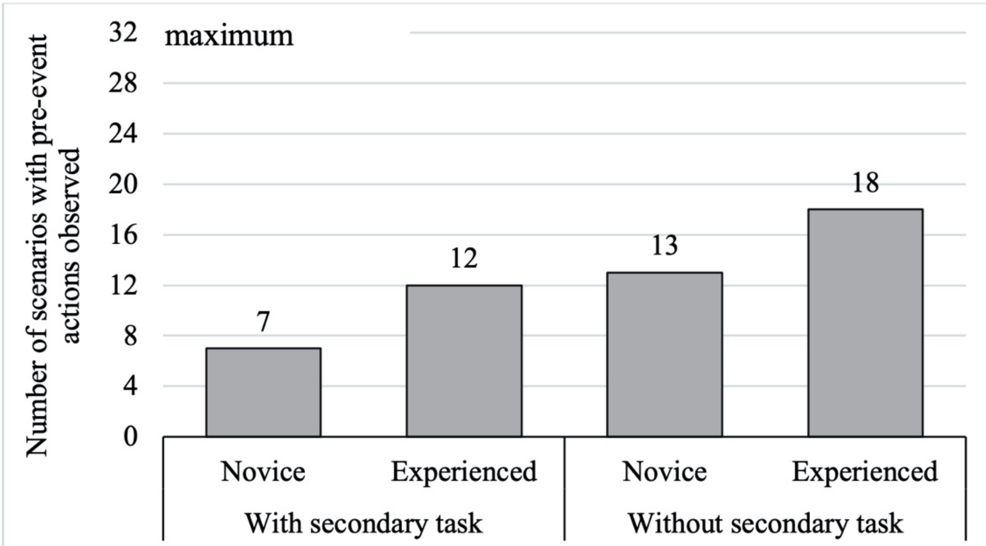


Figure 4. Number of scenarios where a pre-event action was observed across the four experimental conditions; the maximum possible was 32 for each condition (4 scenarios per driver for 8 drivers per condition).

Glance Behaviors

Figure 5 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 post-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 6.

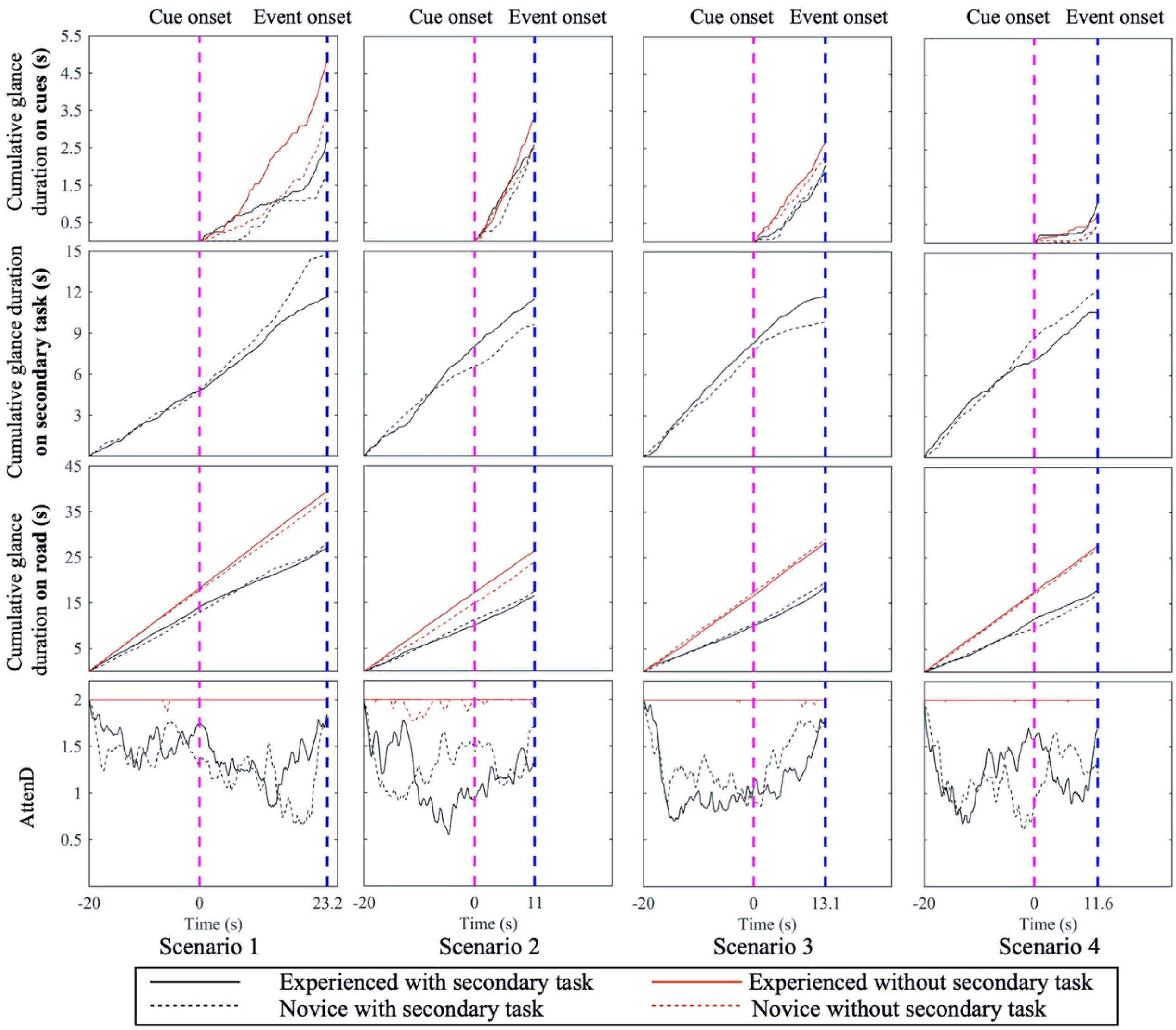


Figure 5. Temporal overview of glances from 20 s before cue onset to event onset: cumulative glance durations on different AOIs and the AttenD averaged across participants. The vertical dash lines represent cue and event onset.

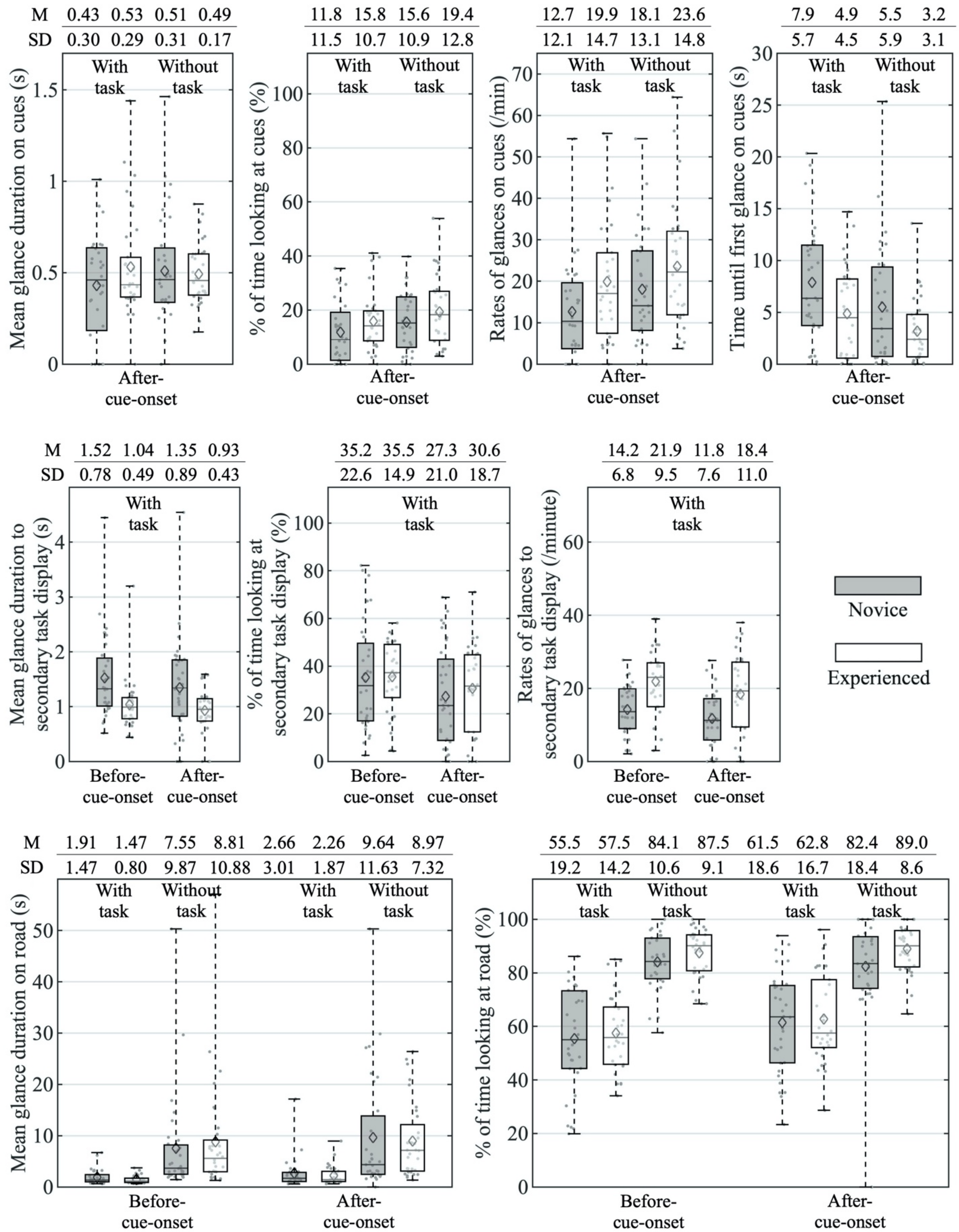


Figure 6. Boxplots of glance metrics. Raw data is presented with grey dots and the means are indicated with hollow diamonds. Mean (M) and standard deviation (SD) values provided at the

top of each graph.

As can be seen in Figure 5, 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 5 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 5 highlight the importance of detailed glance analysis – rather than just capturing at an aggregate level whether drivers are looking on the road or not, we also need to assess where they are looking on the road. The following sections present inferential statistics supporting this assessment; the significant effects are reported ($p<.05$).

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, $F(1, 28.6)=6.90$, $p=.01$, $\omega_p^2 = 0.023$, 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%.

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.

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.

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, $p<.05$.

Relation between Glances and Exhibition of a Pre-event Action

The relation between pre-event actions and glance behaviors were analyzed by comparing glance metrics when there was a pre-event action and where there was none (Table 2 provides descriptive statistics for significant differences). For cue metrics, we focused on data where there was at least one glance toward an anticipatory cue, as this was part of our criteria for identifying a response as a pre-event action; including all data would have introduced a bias in our 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, $\omega_p^2 = 0.044$, 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 2. Descriptive statistics for significant glance metrics for the comparison of drives with and without pre-event actions.

	Drives with pre-event actions Mean (SD)		**Drives without pre-event actions** Mean (SD)	
Glance metrics	*Before-cue-onset*	*Post-cue-onset*	*Before-cue-onset*	*Post-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 1, Samuel and Fisher (2015) found that on-road glance duration plays a role in hazard perception. We assessed if this held true with our dataset, in particular we investigated whether mean on-road glance duration after cue onset predicted whether a pre-event action was exhibited for a given scenario. Further, we also investigated whether mean glance duration on cues provided additional predictive power. For this analysis, we again focused on data where there was at least one glance toward an anticipatory cue, as this was part of our 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.

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), we utilized scenarios that were more complex, where the action of a traffic agent depended and could be anticipated based on the actions of other traffic agents. Similar to our earlier findings utilizing the same approach (Stahl et al., 2014, 2016, 2019), we found experienced drivers to exhibit more anticipatory actions compared to novice drivers, and to have more glances toward traffic cues that facilitate the anticipation of upcoming events (i.e., anticipatory cues). We 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 anticipatory actions – a finding in line with the hazard anticipation study of Muttart et al. (2014) focusing on environmental prediction hazards. Our results also showed that when drivers are engaged in a self-paced visual-manual secondary task, they are less likely to exhibit anticipatory 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, we compared their glances on the secondary task display before and after anticipatory cues became visible. 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, we expected to find an interaction effect, with experienced drivers reducing their secondary task engagement more than novices after cue onset. However, no such effect was observed; given our relatively small sample size, lack of power may have played a role here. It is also possible that unobserved factors (e.g., attention deficit hyperactivity disorder, mind wandering) may have also played a role here; in particular, we observed relatively large variability in glance metrics of novice drivers. Our study 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 anticipatory actions compared to novices. Although both groups were less likely to exhibit anticipatory 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".

We also compared glance behaviours across drives with and without pre-event actions 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), we found that on-road glance duration plays a role in anticipation. In particular we found that mean on-road glance duration is a significant predictor of anticipatory 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 our study provides unique insights into anticipatory driving, it has limitations. We have 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). Our analysis did not assess such carry-over effects that might be significant. Further, the scenarios we used were adopted from our earlier research and thus facilitate comparisons to our earlier findings; however, they represent only a select few situations. In addition, the method we used 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 our experienced participants were slightly older than our novice participants. Due to the age differences in our experience categories, we cannot solely attribute our findings to experience. We did not strictly control for age when recruiting our participants within the different experience groups because we wanted our sample to be representative of the inherent confounds that are present in the driving population, so that we could have 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). Our findings suggest that novice drivers and to a lesser extent experienced drivers need further support, in particular in the presence of distractions. Based on our sample, 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.

Key Points

- Anticipatory driving behaviors are more prevalent among experienced drivers compared to novices and experienced drivers allocate more visual attention to anticipatory cues than novices.
- Distractions, in particular visual-manual secondary tasks, reduce anticipatory driving behaviors and attention to anticipatory cues for both novice and experienced drivers.
- Both novice and experienced drivers reduce their distraction engagement as anticipatory cues become visible.

- Experienced drivers in general appear to have better visual scanning strategies under distraction as evidenced by a lower likelihood of exhibiting long off-road glances and spending more time looking at anticipatory cues on the road.
- Anticipatory actions can be predicted by mean on-road glance duration; however, a better prediction is obtained by also considering mean glance duration on cues. Thus, in addition to how long drivers are looking on the road, how long they are looking at anticipatory cues is an important determinant of proactive actions before traffic conflicts materialize.

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