

THE EFFECTS OF DISTRACTION ON ANTICIPATORY DRIVING

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The anticipation of future events in traffic can allow potential gains in recognition and response times. Anticipatory actions (i.e., actions in preparation for a potential upcoming conflict) have been found to be more prevalent among experienced drivers in a driving simulator study where driving was the sole task. The influence of secondary tasks on anticipatory driving has not yet been investigated, despite the prevalence and negative effects of distraction widely documented in the literature. A driving simulator experiment was conducted with 16 experienced and 16 novice drivers to address this gap with half of the participants provided with a self-paced visual-manual secondary task. More anticipatory actions were observed among experienced drivers in general compared to novices; experienced drivers also exhibited more efficient visual scanning behaviors. Secondary task engagement reduced anticipatory actions for both experienced and novice drivers.

INTRODUCTION

Experienced drivers have reduced crash risks compared to novices (Mayhew, Simpson, & Pak, 2003). With the accumulation of mileage, driving shifts from knowledge- to rule- to skill-based control (Reason, 1990) and drivers gradually become not just better at handling the vehicle (Bjørnskau & Sagberg, 2005) but also better at perceiving hazards on the road (Sagberg & Bjørnskau, 2006). The latter might in part be attributed to their improved capability to anticipate how traffic can evolve in the future (Stahl, Donmez, & Jamieson, 2014b).

The majority of previous studies on anticipation in driving used the lens of hazard perception, e.g., Sagberg and Bjørnskau (2006) and Jackson, Chapman, and Crundall (2009). Stahl et al. considered anticipation from both a perception and a behavior lens, and provided a working definition for anticipatory driving 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., 2014b, p. 605). This definition focuses on anticipation at the tactical level (i.e., within seconds into the future) and emphasizes that anticipatory drivers can be cognitively prepared for future events but may or may not take actions in response. Further, the definition uses the word “efficient”, which is context and driver dependent. That is, the action can both be aggressive or defensive for “efficient” vehicle positioning, depending on the driver goals (e.g., maximizing eco-driving, increasing safety margins, minimizing effort, or reducing travel times).

Regardless of differences in framing, it is agreed that anticipation in driving is a significant element of driver competence that is expected to improve with experience (Jackson et al., 2009; Sagberg & Bjørnskau, 2006; Stahl et al., 2014b). Stahl, Donmez, and Jamieson (2014a, 2016) found experienced drivers to exhibit more anticipatory actions in two separate simulator studies. However, in these studies the sole task of the participant was to drive. Given that anticipation is considered to depend on perception (of hazards or of characteristic cues of stereotypical traffic situations), it is

expected to degrade with activities secondary to driving that compete for the same perceptual resources. It is unclear how anticipatory driving exhibited by novice and experienced drivers would be influenced with distraction. Studies on hazard perception provide some guidance. For example, Sagberg and Bjørnskau (2006) found some evidence to suggest that cognitive distraction degrades hazard perception. As for visual distraction, Borowsky et al. (2015) found that participants who were momentarily visually obstructed often failed to continue scanning for a potential hazard after the obstruction was removed. However, this task was not self-paced and removed the drivers’ ability to moderate their distraction engagement based on their anticipation of a hazard.

As an extension of the work reported in Stahl et al. (2014a, 2016), this research focuses on the influence of distractions on anticipatory driving behaviors of both novice and experienced drivers. As a first step in investigating distractions within this framework, we focus on visual-manual distractions as they are common in driving and the most detrimental to safety (Dingus et al., 2016). Further, we utilize a self-paced secondary task paradigm to enable the drivers to moderate their distraction engagement based on their anticipation of how traffic can evolve.

A driving simulator study was conducted with novice and experienced drivers, with each participant completing four scenarios, with each scenario involving several pre-event cues designed to allow the anticipation of an event. A self-paced visual-manual secondary task, which mimics the operation of in-vehicle infotainment systems (e.g., tuning the radio and operating the navigation system), was provided to half of the novice drivers and half of the experienced drivers. We hypothesized the visual-manual secondary task condition to lead to fewer anticipatory actions in general. However, given that experienced drivers are known to better moderate their off-road glances when engaged in distractions (Wikman, Nieminen, & Summala, 1998), we also hypothesized that, compared to novice drivers, experienced drivers would still exhibit more anticipatory driving actions even when exposed to the secondary task.

METHOD

Participants

A total of 32 (16 female and 16 male) participants completed the study. Participants were mainly recruited through advertisements posted on the University of Toronto campus, in online forums, and nearby residential areas. Half of the participants were novice drivers and the other half were experienced; these groups were balanced for gender. The driving experience criteria were adopted from Stahl et al. (2016). Experienced drivers had a full driver's license (G license in Ontario or equivalent ones in Canada or the U.S.) for at least 8 years with >30,000 km driven in the past year. Due to the difficulty of recruiting experienced participants, the mileage requirement was relaxed to >20,000 km for 1 female participant. Novice drivers had a license (at least G2 license in Ontario, Canada or equivalent ones in Canada or the U.S.) for less than 3 years with <10,000 km driven in the past year. The novice drivers were in general younger than the experienced drivers as presented in Table 1.

The experiment took about 2.5 hours. Participants were told they would be compensated at a rate of \$14/hour, plus a bonus of up to \$8 based on their driving and secondary task performance (the latter for secondary task conditions). All participants received the full bonus regardless of their performance.

Apparatus

The experiment was conducted on a NADS MiniSim Driving Simulator, which is a fixed-based simulator with three 42-inch screens, creating a 130° horizontal and 24° vertical field at a 48-inch viewing distance, with two speakers for stereo sound and a sub-woofer simulating vibration from the road surface. The centre screen displays the left and centre parts of the windshield; the right screen displays the rest of the windshield, the rear-view mirror, the right window, and the right-side mirror; the left screen displays the left window, and the left-side mirror. The driving data (e.g., vehicle speed, brake and accelerator pedal positions, and steering wheel angle) was recorded at a rate of 60 Hz.

A Surface Pro 2 laptop with a 10.6" touch screen was mounted to the right of the dashboard where half of the participants were presented with a secondary task. A Dikablis head-mounted eye tracking system by Ergoneers was used to record participants' visual attention when they were driving, with two cameras facing the eyes and one camera facing forward. Another camera was mounted under the dashboard to record pedal movements.

Experiment Design

As shown in Table 1, the experiment used a 2×2 between-subject design, with driving experience (novice vs. experienced) and secondary task (with vs. without) as independent variables. The different combinations of experience and secondary task led to 4 (2×2) distinct groups of participants, with 8 participants in each group, balanced for

gender (i.e., 4 females and 4 males). Novice and experienced drivers were randomly assigned to different levels of the secondary task factor. Each participant completed four experimental drives; with the secondary task if they were assigned to that group and without the secondary task otherwise. No significant age differences were found across secondary task factor levels for novice ($t(14)=1.55$, $p = .14$) and experienced drivers ($t(14)=1.19$, $p = .26$).

Table 1. Experimental Design and Participant Age

Group: Participant #	Secondary Task	Experience	Mean Age (Min, Max, SD)
1: #1-8	With	Novice	21.8 (19, 27, 2.9)
2: #9-16		Experienced	30.3 (25, 36, 3.9)
3: #17-24	Without	Novice	25.3 (19, 33, 5.2)
4: #25-32		Experienced	33.9 (26, 47, 7.1)

Secondary Task

A visual-manual secondary task developed by Donmez, Boyle, and Lee (2007) was utilized. The task mimicked the operation of in-vehicle information systems such as searching and selecting songs and has been shown to degrade driving performance. Participants were asked to select one out of 10 phrases to match either "Discover" with its first word, "Project" with its second word, or "Missions" with its third word. All phrases consisted of three words and there was only one correct answer in the list of 10 candidate phrases (e.g., "Project Discover Misguide" is not a match, whereas "Discover Missions Predict" is). Two phrases were displayed at one time and participants could tap up and down arrows to scroll through the 10 phrases. Participants pressed a submit button to enter their selection and received feedback on whether their entry was correct or not. A new set of 10 phrases then became available, regardless of the correctness of the submission. The task was available throughout the drive and participants decided when to start a new task and did so by hitting a start button.

Driving Task

Each participant completed four experimental drives, which took about 5-minutes each depending on their speed. The speed limits were 80.5 km/h (50 mph) for rural roads and 96.6 km/h (60 mph) for highways. Participants were instructed to maintain a comfortable distance from lead vehicles and drive around the speed limit. A different anticipatory scenario was presented to the participants in each drive, which was designed to allow for the anticipation of an upcoming event. These scenarios were adopted from Stahl et al. (2014a), and are visualized in Figure 1 and explained below. The order of presentation of the scenarios were kept constant across participants, given that our secondary task variable was administered between subjects and we did not intend to compare the scenarios but rather the experience groups and secondary task levels. Keeping the scenario order constant provided additional experimental control across our factor levels.

The determination of when an event started was dependent on the scenario but was always consistent for a given scenario across participants. The beginning of an event was marked by an action of a lead or overtaking vehicle that would unambiguously indicate the upcoming event, for example, a directional signal. In contrast, cues were ambiguous: they could but did not unambiguously indicate a conflict (e.g., the increase in speed of a following vehicle may indicate a takeover maneuver).

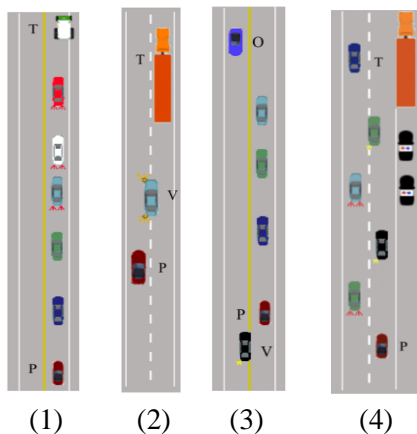


Figure 1. Sketches of the four scenarios experienced by participants. “P” represents the participant vehicle; “T” represents a truck or a tractor; “O” represents oncoming vehicles on the opposing lane; “V” represents other vehicles on the road.

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 five passenger cars traveling at 80.5 km/h. Because of a green tractor traveling at 40.23 km/h (25 mph) in front, the vehicles ahead started to brake consecutively on a curve (the curvature made the tractor visible to the participant). The front-most lead vehicle started to brake when within 22 m of the tractor, with a deceleration of around 7.8 m/s² and the following vehicles braked in succession, with the deceleration decided by the simulator. The event was defined as the brake lights of the vehicle directly ahead of the participant’s vehicle turning on.

The first anticipatory cue was the tractor becoming visible to the participants. The other anticipatory cues were the brake lights of each consecutive vehicle in the chain (except the one directly ahead of the participant’s vehicle). Since all vehicles had to slow down from 80.5 km/h to 40.2 km/h, the visible deceleration and diminishing headway distances between the vehicles were also considered to be anticipatory cues.

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 reached within 210 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 4.9 m/s², to overtake the truck. The event was defined as the signal light onset of the following vehicle.

The changes in speed and the diminishing headway distance between the truck and the following vehicle were considered to be anticipatory cues for the event.

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 event was defined as the right signal onset of the overtaking vehicle.

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. 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.

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 curve made the truck and the police vehicles visible to the participant). 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 4.9 m/s. The cars on the left also braked to make room for merging vehicles with deceleration rates of 4.9 m/s². The event was defined as the left signal and brake light onset (happened at the same time) of the lead vehicle. The anticipatory cue was the truck and the police vehicles becoming visible to the participants.

Procedures

Upon arrival, participant eligibility was verified and consent was obtained. Participants first went through a practice drive in the simulator, on a route similar (in terms of traffic density and road type) to the ones that were going to be used in the experimental drives. The practice drive took at least 5 minutes and lasted until participants felt comfortable with driving in the simulator. The participants assigned to the secondary task condition was then provided with oral and written instructions on the secondary task, followed by a demo, and a practice session on the Surface Pro 2 laptop; they then completed a short practice drive with the secondary task.

After these practice drives, participants completed one more practice drive, but they were told that this was an experimental drive in order to minimize their ability to figure out the purpose of the study. This additional practice drive included two intensive braking events and was not designed to elicit anticipatory behaviors. All participants were told to prioritize driving safety. Participant preparation including practice drives took approximately one hour. Following the

practice drives, participants completed the four experimental drives. Before each drive, the eye-tracker was calibrated. After each drive, participants completed questionnaires on workload and perceived risk and were allowed a 5-minute rest.

Dependent Variables and Statistical Models

In this paper, we present preliminary results on (1) whether participants exhibited actions prior to an event as an indication of an anticipatory action and (2) eye glance behaviors towards the secondary task and anticipatory cues as an indication of visual attention allocation. The statistical models were built in SAS University Edition (v9.4).

For each scenario, participants were grouped into two categories: one in which the participant clearly acted prior to the event, and one in which no clear pre-event action could be identified. Three raters blind to the experimental conditions used videos of the forward view (without participant face) and the feet, along with driving (i.e., speed, pedal position) and glance data (i.e., glances towards cues) to independently judge whether the participant exhibited a pre-event action. Conflicts were resolved in discussions. The number of pre-event actions exhibited across the four scenarios was analyzed in an ordered logit model to examine the odds of exhibiting more pre-event actions. The predictor variables were experience (experienced vs. novice) and secondary task (with and without).

For glances to the secondary task display as well as to anticipatory cues, glance duration was defined from the gaze first intersecting with an area of interest (AOI) to it having moved away from the AOI. Glance durations shorter than 100 ms were not considered as fixations (Crundall & Underwood, 2011) and were excluded from analysis. Table 2 presents the dependent variables used in the analysis of visual attention allocation toward the secondary task display as well as anticipatory cues. It should be noted that 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.

Table 2. Dependent Variables for Visual Attention Allocation

Area of Interest	Dependent Variable	Data Extraction Period
Secondary Task Display	Rate of glances (per minute)	From 20 s prior to the first anticipatory cue becoming visible to the event onset
	Average glance duration	
Anticipatory Cue(s)	Time until first glance	From the first anticipatory cue becoming visible to the event onset
	Rate of glances (per minute)	
	Average glance duration	
	Percentage of time looking	

Given the overdispersion detected in the glance count data, negative binomial regression was used to examine the rates of glances toward the secondary task and anticipatory cues; the data extraction periods were used as the offset variable and repeated measures (four scenarios completed by each participant) were accounted through Generalized Estimating Equations. All other eye glance measures were

modeled using mixed models, with participant introduced as a random factor. For glance measures on the secondary task, the predictor variable was experience. For glance measures on the anticipatory cues, the predictor variables were experience and secondary task.

RESULTS

Anticipatory Actions

The maximum number of pre-event actions a driver could exhibit was 4 (one per scenario). Given that only one driver was identified to have 4 pre-event actions, the data for 4 and 3 pre-event actions were grouped when analyzing number of pre-event actions (Figure 2). Significant differences were observed between novice and experienced drivers ($\chi^2(1) = 5.37, p = .02$) and between secondary task conditions ($\chi^2(1) = 4.25, p = .04$). For experienced drivers, compared with novice drivers, the odds ratio (OR) of exhibiting more pre-event actions was estimated to be 5.14 with the 95% confidence level (CI) ranging from 1.29 to 20.54. Thus, experienced drivers were more likely to exhibit pre-event actions. Further, those who in the secondary task condition, were less likely to exhibit pre-event actions (OR: 0.23, 95% CI: 0.06, 0.93). The interaction effect was not significant ($p > .05$).

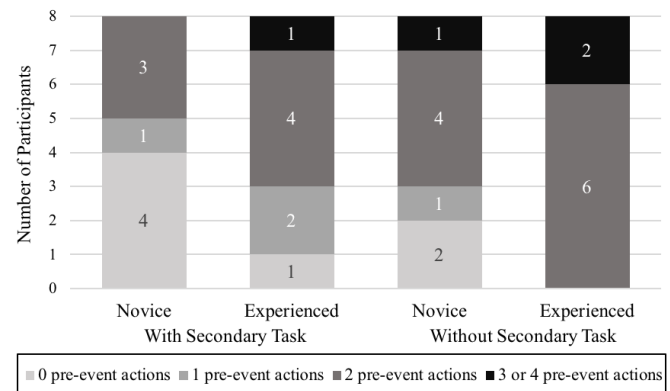


Figure 2. Number of participants who displayed different numbers of pre-event actions within each experimental condition. Number of pre-event actions are indicated using a color gradient with darker shades corresponding to more pre-event actions.

Visual Attention Allocation

Experienced drivers' glance rates toward the secondary task were marginally higher than novice drivers ($\chi^2(1) = 3.42, p = .06$). Experienced drivers' glance durations on the secondary task were marginally significantly lower compared to novices ($F(1,11.9) = 3.53, p = .08$).

Experienced drivers were found to have shorter times until first glance at anticipatory cues ($F(1,118) = 8.18, p = .005$). Further, experienced drivers' glance rates toward anticipatory cues were 50% higher compared to novice drivers ($\chi^2(1) = 8.95, p = .003, 95\% \text{ CI: } 15\%, 96\%$) and experienced drivers spent a larger percentage of time on cues compared to novices (12.7% vs. 9.2%, $F(1,120) = 6.56, p = .01$). No significant effects of secondary task were observed on any of

these glance measures on anticipatory cues, and no significant effects were observed in general for average glance duration.

To further analyze whether secondary task glances were influenced by anticipation, the drivers were categorized into two groups: those who exhibited 2 or more pre-event actions (“higher-anticipation drivers”) and those who exhibited 1 or no pre-event action (“lower-anticipation drivers”). The models reported above were re-ran with this new variable as the only predictor; the other predictors were excluded to prevent multicollinearity. No effects were found on glances toward the secondary task. Higher-anticipation drivers took significantly less time to first glance at cues ($F(1,120) = 22.47, p < .0001$), had larger rates of glances towards cues ($\chi^2(1) = 15.89, p < .0001$), and spent a higher percentage of time looking at the cues (13.2% vs. 6.5%, $F(1,122) = 23.53, p < .0001$).

DISCUSSION

A driving simulator study was conducted to investigate the effects of visual-manual secondary tasks on drivers’ anticipatory actions, for both experienced and novice drivers. Similar to the findings of Stahl et al. (2014a, 2016), we found experienced drivers to exhibit more pre-event actions compared to novice drivers, using a similar proxy implemented by Stahl et al. (2014a, 2016) for capturing anticipatory actions. Further, as a novel contribution, we found that when drivers engage in a self-paced visual-manual task, they are less likely to exhibit pre-event actions. Although the presence of a self-paced secondary task reduced the prevalence of pre-event actions for both novice and experienced drivers, no significant interaction effect was observed. According to Wikman et al. (1998), experienced drivers are better at adapting their visual attention when distracted. Thus, one might expect that experienced drivers should have been influenced less by the presence of the secondary task. The lack of significance might be due to a lack of statistical power. With an increased sample size, interaction effects may become significant.

Our glance analysis supports the role visual attention plays in anticipatory driving. Those who had more pre-event actions, i.e., the higher-anticipation group, took significantly less time to first glance at anticipatory cues, had larger rates of glances towards these cues, and spent a higher percentage of time looking at them. Similar findings were observed for experienced drivers when compared to novices. Overall, experienced drivers’ visual scanning behaviors are known to better match the complexity of the traffic environment (Underwood, 2007).

An interesting finding was the lack of significance of secondary task condition for glance measures on anticipatory cues, including time until the first glance, rate of glances, and percentage of time looking toward the cues. One would expect that engagement in a visual-manual secondary task would interfere with glances toward anticipatory cues. However, no effects were observed for these glance measures between drivers who were provided with the secondary task and those who were not, despite the fact that there were differences between these groups in anticipatory actions taken. This lack of significance may be due to sample size, but given that we

were able to identify other significant main effects, this lack of significance may also be due to the fact that drivers with the secondary task may have “looked but did not see”. Our secondary task was primarily visual-manual in nature, but it likely claimed additional cognitive resources. Thus, even if the drivers who had the secondary task may have glanced at cues in a similar pattern to those who did not have the task; the secondary task may have resulted in a reduced spare cognitive capacity required to interpret the situation or act upon it, leading to less anticipatory actions. In the presence of the secondary task, the driver goals may have also shifted, with anticipatory drivers becoming less active in exhibiting anticipatory actions even if they interpreted the situation correctly. This finding and explanations provide further support to the information-processing-based framework proposed by Stahl et al. (2014b), which has perception, interpretation, and action among its components. A purely cognitive secondary task can be used to further explore these hypotheses and framework.

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