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Eye glances towards conflict-relevant cues: the roles of anticipatory competence and driver experience

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ABSTRACT

Objective: This paper analyzes the effects of anticipatory competence and driver experience on glance patterns towards visual cues that indicate conflict situations. *Background*: Prior research has shown that experienced drivers' visual scanning patterns differ from those of novices. Experienced drivers are less erratic and more systematic in their monitoring of the environment. We have also shown in an earlier study that driving experience improves anticipatory competence in that it leads to a higher number of timely proactive actions in conflict-scenarios (avoidance actions prior to, as opposed to in reaction to a conflict). This paper investigates glance patterns specifically to relevant visual cues in conflict scenarios to determine whether glance patterns of anticipatory drivers who exhibit proactive actions differ from those who do not. It also investigates whether experienced drivers pay more attention to these cues compared to novices. *Method*: We conducted a simulator experiment with 24 experienced and 24 novice drivers. As part of the experiment, all drivers completed three distinct traffic scenarios, each with a conflict situation. *Results*: The results show that drivers who exhibited proactive actions had more frequent and longer glances towards conflict-relevant cues than those who did not exhibit any. Similarly, experienced drivers focused on these visual cues more often, and for longer durations compared to novices. Further, experienced drivers who exhibited proactive actions looked at the cues more often compared to experienced drivers who did not exhibit any; there was no significant difference for novice drivers. *Conclusion*: These findings speak to the role of situation-specific visual cues for anticipatory competence, and to the importance of driver experience to aid in the interpretation of these cues. Future research should seek to confirm our findings in a wider variety of driving scenarios.

1. Introduction

Driving is a highly visual task, requiring continual monitoring of vehicle position relative to the roadway. The majority of the information about other traffic participants, traffic infrastructure, traffic regulations, and vehicle status is also communicated through the visual channel. Overall, visual information is estimated to make up the majority of the total information available to drivers (Hills, 1980). Not surprisingly then, poor visual scanning and errors with respect to the perception of the traffic environment have been reported as major causes of crashes (Sabey and Taylor, 1980). Research into crash statistics has shown improper visual search to be consistently among the top contributors, for example ranking as the third most frequent reason (after lack of attention and wrong speed choice) in a study conducted on more than 2000 crash reports from the states of California and Maryland (McKnight and McKnight, 2003). Given the importance of correct visual perception of the roadway, the investigation of drivers' glance patterns has become a major aspect of driver behaviour research.

It is also well known that young, novice drivers are overrepresented in crash statistics (Jonah, 1986). While initially this overrepresentation was seen as a consequence of factors such as risk-seeking behaviour, drug abuse, or night time driving, more recently visual search and the correct interpretation of the roadway have been argued to be the deciding factors (Fisher and Pollatsek, 2006; Pollatsek et al., 2006). Novice drivers' failure to correctly interpret the roadway and its upcoming risks (Pollatsek et al., 2006) may stem in part from a general lack of exposure to similar traffic situations, but also from failures in visual search. Driving experience in turn, aids not just in the efficient allocation of attentional resources to detect potential hazards, but also in the successful prioritization thereof (Pammer et al., 2018). As a consequence, experienced drivers show reduced crash risks in comparison to novice drivers (Mayhew et al., 2003).

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1.1. Anticipatory driving competence

Anticipatory driving competence describes the ability of a skilled driver to predict future states of the surrounding traffic situation, and act on this anticipated state before conflicts can establish themselves (Stahl et al., 2014). Anticipation can therefore be beneficial for safety – the sooner conflicts in the roadway can be identified, the more time and space is available for what Fuller (1984) labels an "anticipatory avoidance response". But anticipation can also be beneficial in other ways, such as in eco-driving. Studies investigating the use of anticipation to maximize coasting times and minimize brake usage estimate that about 10% of fuel can be saved in this manner (Thisjen et al., 2014; Rommerskirchen et al., 2013; Baer et al., 2011).

We have defined anticipatory driving as "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). This understanding of anticipation allocates a crucial role to the visual perception of cues, which allows for the recognition of a given situation by comparing it to a stereotypical model of that situation. Anticipatory drivers pick up on important cues due to their cognitive processing of the situation, which in turn allows them to scan more effectively for additional cues. The result is a detailed assessment of the situation, and active projection of its development into the near future.

In prior research, we investigated anticipatory competence in a driving simulator study and found that within the simulator scenarios tested, anticipatory driving had the potential to improve general driving safety, as documented by on average longer minimum time to collision (Stahl et al., 2014). We also learned that experience, as determined by years of licensure and annual mileage, improves anticipatory driving competence. Experienced drivers can be argued to have a better-established, larger store of reference stereotypical situations, therefore facilitating their interpretation of a given situation. They are therefore more skilled at interpreting cues quickly, and have been shown to react faster in terms of time to fixation and perception-response time when mitigating hazards (Upahita et al., 2018).

In our prior work, we identified anticipatory drivers exclusively through their driving performance; that is, through actions that were taken prior to a given conflict event. We labeled these actions in a given scenario as pre-event actions (Stahl et al., 2014). However, we also expect visual search patterns of anticipatory drivers to differ from those of non-anticipatory drivers. This expectation stems from the importance of visual cues for the identification of stereotypical situations, which in turn enables anticipation of the future development of those situations. Gaze patterns have also been investigated in the context of hazard perception, and led to the conclusion that experienced drivers attend to risky areas of the traffic situation more so than novice drivers do (Pradhan et al., 2005).

With the experiment described in this paper, we again assessed anticipation through the timing of participants' actions relative to specific conflict events in a given scenario. Beyond the monitoring of participants' pre-event actions, we also collected eye-tracking data to investigate whether there were systematic differences in visual search between participants who do and do not exhibit those pre-event actions. While it is possible for a skilled driver to recognize relevant cues, correctly understand the situation at hand and anticipate a likely conflict, but choose to not act (for example because a crash is not yet imminent), it should not be possible for a driver to understand the situation correctly and exhibit an anticipatory pre-event action without having attended to the cues indicating the situation.

1.2. Experience-related differences in visual scanning

Experienced drivers are generally argued to have superior visual scanning compared to novice drivers (Jackson et al., 2009; Pollatsek et al., 2006). One of the first studies on drivers' eye movements concluded that novice drivers' visual information acquisition was lacking skill in comparison to experienced drivers: their fixations covered a relatively small area, were mostly directly towards the front of the vehicle, and covered a significantly smaller horizontal range (Mourant and Rockwell, 1972). Later research identified that experienced drivers varied the width of their horizontal scanning to accommodate differing complexities in roadways, while novice drivers did not exhibit this behaviour (Crundall and Underwood, 1998).

Pradhan et al. (2005) reported superior visual scanning for older participants, a factor that usually correlates with experience. They investigated the performance of 24 novice (less than six months licensure), 24 young (19–29 years old), and 24 older drivers (60–75 years old) across 16 risky scenarios in a driving simulator, analyzing whether or not participants fixated on risky features of the scenarios. Their analysis indicated that these three groups of drivers, i.e., novice, young, and older, showed behaviour indicating they had recognized a risk 35.1%, 50.3%, and 66.2% of the time, respectively. Experience gained through driver training has also been shown to have positive effects on visual scanning patterns. Fisher et al. (2007) showed that drivers trained on a PC program to recognize risks transferred that skill to both simulated and on-road driving. In both settings, trained drivers achieved a higher percentage of fixations on regions that held risk-relevant information compared to drivers without training.

The studies mentioned above suggest that driver experience results in several benefits with respect to visual scanning patterns: horizontal scanning covers a wider width, fixations cover a larger area and are usually further away from the vehicle, and scanning patterns become generally more flexible and change relative to the situation at hand. With respect to hazard detection, areas indicative of the risks contained in a given scenario are fixated upon more often. While previous research had already shown the effect of driving experience on the ability to anticipate, the present research focused on assessing whether visual scanning patterns differ for anticipatory drivers, and whether the glance pattern of an experienced, anticipatory driver might deviate even from that of an experienced, but non-anticipatory driver. To this end, we extended the existing investigations of the general eye-tracking patterns of drivers (both novice and experienced) with a driving simulator study specifically assessing glance patterns towards context-dependent visual cues that are relevant for the anticipation of traffic. In particular, our theoretical considerations of anticipation and observation of participants in our first experiment (Stahl et al., 2014) led us to hypothesize that drivers exhibiting pre-event actions compared to those who do not, and experienced drivers compared to novices, would attend to conflict-relevant cues more.

2. Methods

The data presented in this paper come from a larger driving simulator experiment that, in addition to examining the effect of driver experience on anticipatory driving, also investigated how interface interventions can facilitate anticipatory driving. The details of this larger experiment and the interface intervention results are presented in Stahl, Donmez, and Jamieson (2016). In the current paper, we concentrate only on the baseline data from this experiment, in which participants were not yet presented with an interface intervention. Further, this earlier paper did not investigate glance behaviours towards conflict-relevant cues, which is the focus of the current paper.

2.1. Participants

Forty-eight participants completed the driving simulator experiment: 12 female and 36 male, both groups with equal splits between novice and experienced drivers. All participants held at least a valid G1-level license in the province of Ontario (or an equivalent license allowing them to drive when accompanied by a fully licensed driver) and

Table 1
Two levels of driver experience investigated in the experiment.

Driving experience	Years of licensure	Distance driven within past 12-months (km/year)	n	Mean age (SD)	Age range
novice	≤3	< 10,000	24	19.5 (2.19)	18– 27
experienced	≥8	> 50,000	24	40.2 (14.23)	23–76

had driven a passenger vehicle with an automatic transmission. Both novice and experienced drivers were recruited for the study within the experience categories defined in Table 1. Most participants were recruited from the student body of the University of Toronto or through a Canadian driver training organization, although we also advertised on social media and networking services. All participants filled out an online screening questionnaire to determine eligibility for the study.

2.2. Experimental design

Driver experience, a between subject variable, is the only independent variable in the current analysis, and has two levels defined based on years of licensure (i.e., years a valid driver's license has been held) and annual mileage (i.e., distance driven within the previous 12 months; Table 1). These categories are similar to the ones used in our earlier driving simulator study (Stahl et al., 2014) with the exception that the medium-experience level was merged with high-experience level as our previous study did not find differences between these two levels. Further, due to the difficulty in recruiting participants, we relaxed the number of years of licensure required for both groups, requiring the low experience group to have held a license for a maximum of three years, and the high experience group for a minimum of eight years, whereas in Stahl et al. (2014) we used two and ten years, respectively.

2.3. Apparatus

The simulator used was a PC-based, quarter-cab NADS MiniSim research driving simulator (Fig. 1), with three 42-inch plasma TVs to create one combined display spanning a 130° horizontal and 24° vertical field of view at a 48-inch viewing distance. An additional 19-inch screen integrated into the dash displayed speedometer and revolution meter. The simulator used an authentic steering wheel, column gear selector, pedals, and vehicle seat. While steering wheel and pedals had realistic resistance forces, neither were capable of dynamically changing those forces to simulate road feedback (such as the high frequency feedback that can be felt in the brake pedal of a real car when performing an emergency braking maneuver using ABS, for example). Stereo sound of the vehicle and its surroundings was portrayed through two speakers in the front; a third speaker mounted below the driver seat simulated roadway vibrations. Audio volume was set such that road and engine noises were deemed realistic by the experimenter. The simulator collected driver performance measures at 60 Hz, and was equipped with a four-channel video capture system. A dashboard mounted Seeing Machines Facelab 5.1 Eyetracker collected gaze data at 60 Hz. All data generated from the eye tracking system were automatically linked with the driving simulator through the faceLAB software package. EyeWorks, another software tool, was incorporated into the system and served to overlay a visual, synchronized indicator for participants' gaze location over the simulated environment (of just the center screen) in the driving simulator.

Fig. 1. NADS MiniSim driving simulator.

2.4. Driving scenarios

For the baseline condition reported in this paper, each participant completed three scenarios in the same order, with a new drive starting for each scenario. The scenarios were adapted from our previous experiment (Stahl et al., 2014), and participants were instructed to 1) maintain a relatively constant speed around the speed limit of 60 mph when traveling on the highway, and 2) maintain a comfortable distance when instructed to follow a lead vehicle without overtaking. These instructions were important to ensure as similar an experience between participants as possible, since scenarios were defined via trigger actions relative to the participant vehicle. While the succession of events within a scenario was always the same, variations in speed chosen by the participant could have resulted in different headway distances at the time of an event.

2.4.1. Scenario 1 - Stranded truck on highway shoulder

For this scenario, the participants found themselves in the left lane of a four-lane divided highway, following a stream of vehicles (which maintained 55 mph). A stranded truck on the highway shoulder was visible from a distance of 500 m (at an approximate visual angle, VA, of 0.48°). Upon approaching the truck on the shoulder, the vehicles in front of the participant started merging left (all of them using their signals for 2 s before starting lateral movement) to safely pass the truck on the shoulder, thereby resulting in a chain of braking events in both lanes. Deceleration rates were not specified by the investigator, but were left to the simulator artificial intelligence with the goal of maintaining a time to collision of 6 s between all vehicles. The event – that is, our threshold to differentiate between a pre- vs. post-event action – was based on the behaviour of the vehicle immediately in front of the participant vehicle in the right lane, which in reaction to cars braking and merging into the left lane braked and merged left itself (see Fig. 2 for a depiction of each scenario at the corresponding event). We defined

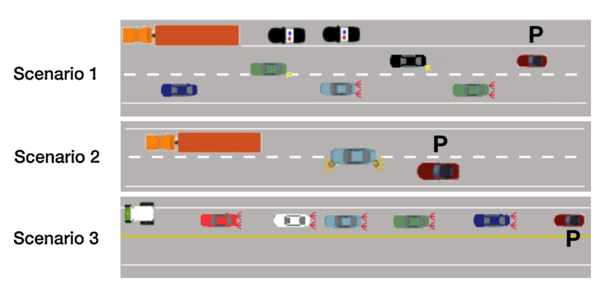

Fig. 2. Graphic outlining simulator driving scenarios at the time of the event; participant vehicle highlighted with letter "P".

Table 2
Visual cues that could support the anticipation of the event within each experimental scenario.

Scenario number and name	Visual cues
#1: Stranded truck on highway shoulder	• Stranded truck on shoulder • Brake lights of any vehicle ahead (except vehicle directly ahead) • Left turn signal of any vehicle ahead indicating a merge from the right into the left lane (except vehicle directly ahead)
#2: Slow moving traffic on the highway	• Slow car in the right lane • Slower truck in the right lane • Diminishing headway between the car and the truck
#3: Chain-braking due to a slow tractor	• Slow tractor which appeared in the visual scene initially covered by several trees and then moved into vision • Brake lights of any vehicle ahead (except vehicle directly ahead)

the event to be the activation of the left turn signal of this car. The cues that would support the anticipation of this event as well as the events of Scenarios 2 and 3 are listed in Table 2.

2.4.2. Scenario 2 - Slow moving traffic on the highway

For this scenario, the participant was driving on either lane of a four-lane divided highway with no vehicle ahead (and thus was instructed to maintain 60 mph). The participant then approached two vehicles that were in the right lane: one vehicle directly ahead and traveling at 80% of the participant's speed (first visible at VA ˜ 0.24°) and a semi-trailer truck ahead of this vehicle traveling at 66% of the participant's speed (first visible at VA ˜ 0.48°). Once the distance to the vehicle ahead fell below 122 m, the speed of the truck was set to 40 mph, and the speed of the vehicle ahead was set to 47 mph. Thus, the vehicle ahead was approaching the truck as the participant approached both vehicles. The vehicle ahead signaled for 2 s and then pulled out into the left lane (accelerating to 50 mph at a rate of 2 m/s^2) to overtake the truck as soon as the participant vehicle was within 76 m of the vehicle ahead. We defined the event as the left turn-signal onset of the vehicle ahead, which was followed by this vehicle overtaking the truck.

2.4.3. Scenario 3 - Chain-braking due to a slow tractor

The participant was asked to follow a chain of five passenger vehicles travelling at 40 mph into a curve on a two-lane rural road, with opposing traffic. Due to a tractor travelling at 20 mph, initially 300 m ahead of the first car (VA ∼ 0.72°), the vehicles started to brake consecutively (1^{st} car when within 70 m from the tractor and at a deceleration of 1 m/s^2, 2^{nd} car when within 21 m of the 1^{st} car at 2 m/s^2, 3^{rd} car when within 24 m of the 2^{nd} car at 2.5 m/s^2, 4^{th} car when within 21 m of the 3^{rd} car at 2.5 m/s^2, and the last car when within 37 m of the 4^{th} car at 2.5 m/s^2). This chain braking required the participant to reduce speed as well. The event in this scenario was defined as the braking of the vehicle directly ahead of the participant (Fig. 2). If the participants had not yet acted and decelerated up until this point, they had to act now to avoid collision.

2.5. Procedure

Participants were told that the general purpose was to study driving behaviour in a simulator environment. An informed consent form was then given, which detailed the experimental procedure and risks. Care was taken to never inform participants about what parts of their driving behaviour specifically were relevant for the study. After signing the informed consent document, the investigator allowed the participants to adjust the steering wheel, backrest, and seat positions, and explained the controls of the simulator. Participants were then told that the default highway speed was 60 mph, and not to overtake lead vehicles. Participants then had two practice runs to familiarize themselves with the simulator and train for these default behaviours. The first practice run gave them an opportunity to drive on a rural road below 40 mph and follow a lead vehicle, while the second one involved a merge onto a highway as well as practice at maintaining a highway speed of approximately 60 mph. The practice session took approximately 10 min in total and ended when the participant and the experimenter were both content with the participants' ability to pilot the car, as well as maintain constant speed (which as explained before was important to between-subject comparability of scenarios). Following the practice session, the investigator calibrated the eye-tracker. The participant then completed the three drives (Scenario 1, Scenario 2, and Scenario3), each one lasting three to five minutes. The experiment took approximately 45 min up to this point, which consisted of the baseline condition of the larger study presented in Stahl et al. (2016). The total participation time for the larger study varied between 1.5 and 2 h with CAN$20 in compensation.

3. Results

3.1. Pre-event actions indicating anticipation

Drivers were categorized into pre- and post-event response groups based on whether or not they acted prior to the event defined in each scenario using the same methods employed in Stahl et al. (2014). During this categorization process, the coder was blind to all information about the specific driver, including what driving experience a given driver had. Given that there were three scenarios completed by each driver, a highly anticipatory driver could reach a maximum of three pre-event actions overall. Deceleration was always considered an appropriate pre-event action, and in fact was the only pre-event action we observed from participants in Scenarios 1 and 3. In Scenario 2, some participants also accelerated to pass the vehicle ahead before it signaled its lane change to overtake the slower truck, which was also considered a pre-event action.

As shown in Fig. 3, novice drivers exhibited few pre-event actions. Sixteen of the 24 novice drivers did not act before any of the events taking place, and only eight had one pre-event action. We did not observe any novices with more than one pre-event action. Experienced drivers in contrast exhibited more pre-event actions. For statistical analysis, we re-categorized these data given that there were only a small number of participants with two and three pre-event actions (only nine experienced drivers). The resulting dependent variable was binary in nature, distinguishing between participants who did (≥1 pre-event

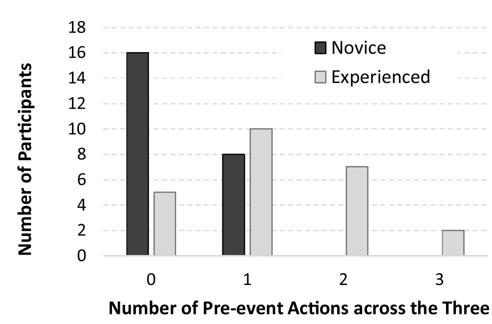

Fig. 3. Number of novice and experienced participants who displayed different numbers of pre-event actions (maximum possible was three).

actions) and who did not exhibit pre-event actions (0 pre-event actions) across the three scenarios tested. A logistic regression model was built on these data to assess the relation of experience and pre-event actions. The model was fitted using PROC GENMOD in SAS 9.3, with the specifications of logit link function and binomial distribution. The results showed that experienced drivers exhibited pre-event actions with more than sevenfold the odds compared to novices, Odds Ratio = 7.60, $\chi^2(1) = 9.35$, $p = .002$.

The method used in this paper as well as in our earlier study (Stahl et al., 2014) identified anticipation through pre-event actions. A pre-event action is hypothesized to result from anticipation but albeit is not a direct measure of it. There might be drivers who act pre-event by coincidence, for example by decelerating to regulate headway in just the moment when deceleration would also be favorable to prepare for a lead vehicle braking event due to some obstacle further ahead. Eye-tracking data can help weed out some of these cases; at least to the extent that it can confirm visual glances towards, and therefore also a heightened likelihood of attention to, a given cue. A driver exhibiting a pre-event action without having processed any of the relevant visual cues cannot be using anticipatory competence. We analyzed our glance data with this perspective and found that in each of the three scenarios, all of the participants who exhibited a pre-event action had glanced to (i.e., had a glance ≥120 ms) at least one cue. In contrast, among the participants who did not exhibit a pre-event action, the percentage of those who also did not look at any of the cues was 50%, 38%, and 64% for Scenarios 1, 2, and 3, respectively.

3.2. *The influence of anticipatory competence and experience on glances towards conflict-relevant cues*

Onset and offset times of glances towards conflict-relevant cues were coded manually through the analysis of EyeWorks videos, which overlaid gaze fixations on the simulator video feed during data collection. The portion of the videos analyzed for each scenario started when the first cue appeared on the screen and stopped with the event onset (e.g., vehicle turn signal onset in Scenario 1). The first two scenarios were coded solely by the primary author. For the third scenario, an undergraduate and a graduate student assisted with video coding, both to aid with quicker processing of the data and to ensure that the primary author's interpretation of the video data was not biased. Inter-rater reliability was tested on three videos that all three raters had processed by comparing glance onset and offset times. Given the continuous nature of the data, we used Krippendorff's α (Hayes and Krippendorff, 2007). Ratings were excellent for both the onset (α = 1) and the offset times (α = .99).

We then extracted three eye glance measures, namely the total number of glances towards cues across the three scenarios, mean length of these glances, and maximum length of glances towards these cues. We chose these measures because we were primarily interested in how much attention was being allocated to the cues (as opposed to visual search paths or the sequence in which cues were fixated upon). All glance measures were generated according to ISO definitions (ISO/FDIS, 2013).

General linear models were built in SAS 9.3 with the PROC MIXED procedure, separately testing the relation of number of pre-event actions and driver experience with the glance measures. We refrained from including the two explanatory variables in the same models to avoid issues of multicollinearity, having established in this dataset a significant association of experience with pre-event actions as reported in the previous section. Results showed that experience was significant for all three eye-glance measures (Fig. 4). Experience increased glance frequency, with experienced drivers looking at cues on average 20.5 times across the three scenarios, and novice drivers on average 4.7 times, $t(45) = 6.55$, $p < .0001$ (Fig. 4a). Further, experienced drivers spent on average 0.80 s per glance looking at the cues and novices spent on average 0.22 s per glance, $t(45) = 6.72$, $p < .0001$ (Fig. 4b). Finally, maximum glance length also differed significantly, with experienced drivers having on the average a maximum glance length of 2.21 s, and novice drivers having an average maximum glance length of 0.96 s, $t(45) = 4.45$, $p < .0001$ (Fig. 4c).

The results also showed that pre-event responders (i.e., drivers who exhibited ≥1 pre-event response) glanced at conflict-relevant cues more frequently than the non-responders (i.e., drivers with 0 pre-event responses), with an average of 18.2 vs. 5.3 glances over the three scenarios, $t(45) = 4.56$, $p < .0001$ (Fig. 4d). Pre-event responders also had larger mean and maximum glance lengths compared to the non-responders. Average mean glance length for the pre-event responders was 0.68 s compared to 0.28 s for the non-responders, $t(45) = 3.88$, $p = .0003$ (Fig. 4e), and average maximum glance length was 2.03 s for pre-event responders compared to 1.00 s for non-responders, $t(45) = 3.41$, $p = .001$ (Fig. 4f).

To investigate interaction effects, we collapsed both explanatory variables into one combined explanatory variable with four levels: experienced drivers without pre-event actions, experienced drivers with pre-event actions, novice drivers without pre-event actions, and finally novice drivers with pre-event actions. The associated boxplots are displayed in Fig. 5. Graphical results again show that experienced drivers appear to glance more frequently and longer towards the cues, as do participants who exhibit pre-event actions. However, it can also be seen that differences between the two novice driver groups are relatively small for all three dependent variables. Experienced drivers with pre-event actions in contrast appear to glance more frequently, and with longer mean and maximum glance durations than experienced drivers who did not exhibit pre-event actions.

Statistics confirmed the visual impressions with significant main effects on total number of glances, $F(3, 43) = 25.94$, $p < .0001$, mean glance length, $F(3, 43) = 17.29$, $p < .0001$, and maximum glance length, $F(3, 43) = 8.19$, $p = .0002$. Follow-up comparisons were performed with p-values adjusted through the Tukey-Kramer method. For total number of glances, experienced drivers with pre-event actions glanced on average 23.9 times, while experienced drivers without pre-event actions glanced only 8.4 times, $t(43) = 4.33$, $p = .0005$. Experienced drivers with pre-event actions also differed significantly from novice drivers with pre-event actions, $t(43) = 6.20$, $p < .0001$, and novice drivers without pre-event actions, $t(43) = 8.03$, $p < .0001$, who glanced 5.3 and 4.4 times, respectively. For mean glance length, experienced drivers with pre-event actions glanced on average for 0.85 s, which was significantly longer than novice drivers with, $t(43) = 4.47$, $p = .0003$, and without pre-event actions, $t(43) = 6.87$, $p < .0001$, who glanced for 0.31 and 0.18 s, respectively. Experienced drivers without pre-event actions glanced on average for 0.59 s, which was significantly longer than novice drivers without pre-event actions, $t(43) = 2.84$, $p = .03$. Finally, maximum glance duration of experienced drivers with pre-event actions was 2.39 s on average and was significantly longer than novice drivers with pre-event actions, $t(43) = 2.88$, $p = .03$, and novice drivers without pre-event actions, $t(43) = 4.82$, $p < .0001$, who had average maximum glance durations of 1.23 s and 0.82 s, respectively.

4. Discussion

The focus of this paper was the investigation of glance patterns towards important situational cues in traffic. We have seen that the display of anticipatory competence, as measured by the number of pre-event actions that participants exhibited, was also characterized by glance patterns. Anticipatory drivers, i.e., drivers who had pre-event actions, looked at relevant cues more often, were focused on those cues for longer, and exhibited longer maximum glance lengths towards them. Given that experienced drivers have been found to use superior scanning patterns (Pradhan et al., 2005), and in light of the correlation between experience and anticipation, this result is not surprising. More importantly, this result is in line with the hypothesized importance of

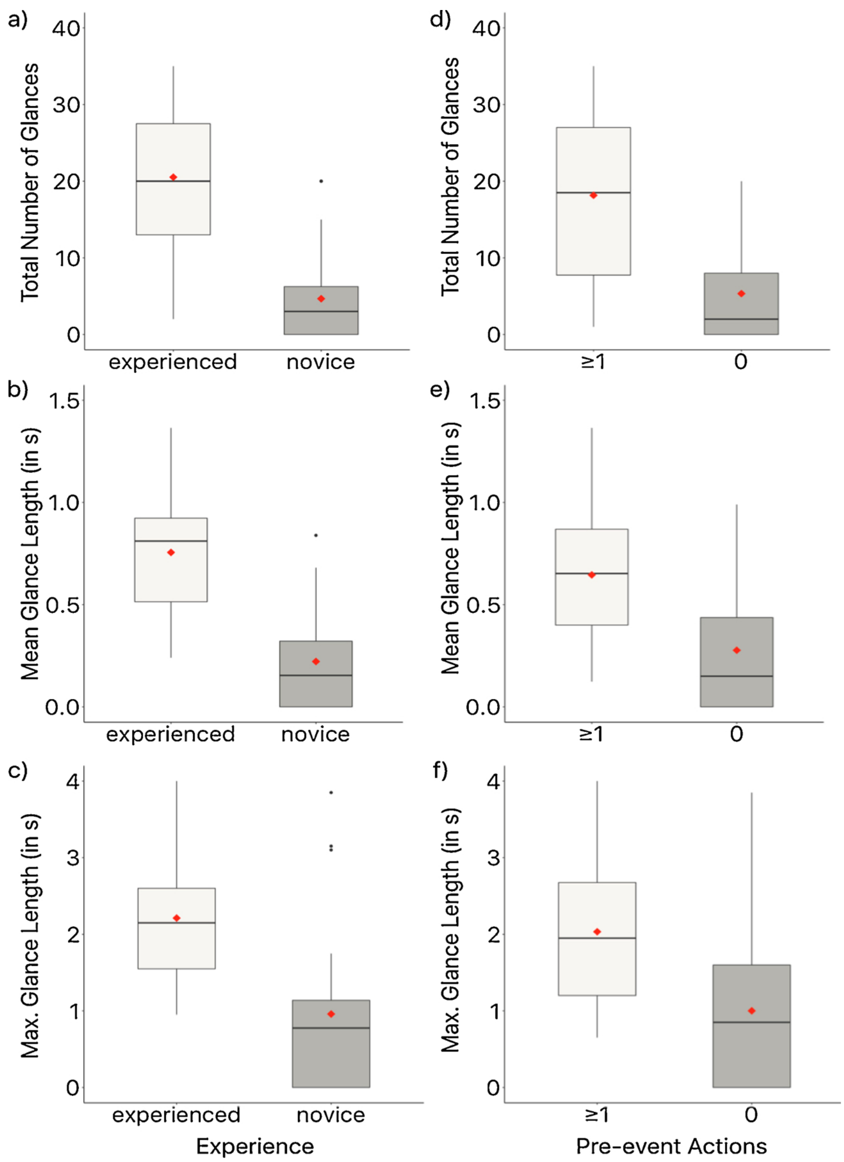

Fig. 4. Boxplots of a) total number of glances (across three scenarios), b) mean glance length, and c) maximum glance length towards the cues across the two experience categories, as well as d) total number of glances, e) mean glance length, and f) maximum glance length towards the cues across number of pre-event actions (these and following boxplots present minimum, first quartile, median, third quartile, and maximum, as well as potential outliers indicated with circles outside boxes and means indicated with solid circles inside boxes).

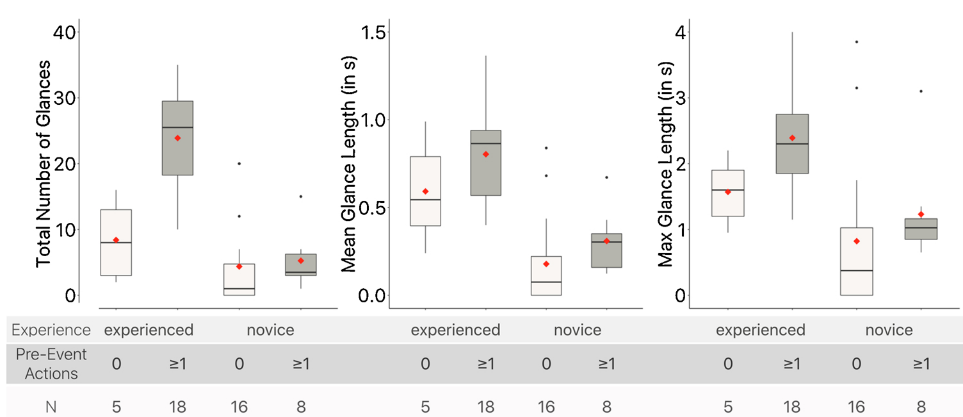

Fig. 5. Boxplots of total number of glances towards relevant cues, mean glance length, and maximum glance length across experience and number of pre-event actions.

visual cues for anticipation. Recognizing relevant visual cues is a necessary initial step towards the correct interpretation of a given traffic situation, and this understanding in turn enables predictions about the future development of that situation. This importance of cue recognition was further strengthened by confirming that no participants had shown pre-event actions without glances towards the cues: in all instances where participants exhibited pre-event actions they also looked at the cues that were indicative of the situation.

Care needs to be taken, however, to not rely on gaze data alone to assess anticipation, due to the difficulties of using glance patterns to deduce cognitive processes such as anticipation. While we theorize that the perception of cues is a necessary condition for a correct situational assessment and the anticipation of future, mere cue-recognition as proven by eye-tracking is not a sufficient condition for correct situational assessment. Further, the eye-tracking measures we collected are limited in that they represent only foveal vision. The useful field of view however is as large as 30°, and studies into visual conspicuity have shown that targets smaller than 1° in angular size are usually noticed when they are less than 10° off the line of sight (Cole and Hughes, 1984). Drivers may therefore be able to attend to cues even if eye-glance patterns do not directly fall on those cues. In the scenarios described in our experiment, cues were often very small in size (several cues were below 1° in angular size), so that future research may profit from defining appropriate target areas around such small visual cues, thereby accounting for the potential of cues being actively monitored even when not in focus. Further, in our earlier work, we have noted the possibility of passive anticipation, that is, drivers consciously deciding not to act upon a correctly anticipated scenario (Stahl et al., 2014). While we did not find hints for this behaviour in our current data, or in post-experiment cognitive walkthroughs with participants, particularly aggressive drivers could potentially not perceive the likelihood and severity of the upcoming conflict as high enough to act. In this case, drivers would not exhibit a pre-event action, but still show the eye-glance patterns of an anticipatory driver. In our experiment, these participants would be among those without pre-event action, and obscure an otherwise potentially clear differentiation of eye-glance patterns between anticipatory and non-anticipatory drivers. Future research could seek to investigate more dangerous conflict scenarios, and establish how dependent favorable-anticipatory actions are on the risk tolerance of individual drivers.

Eye-tracking is an important tool for the study of driver behaviour, but due to the issues identified above, causal conclusions should not be based on the assessment of eye-glances exclusively. We see the utility of eye-tracking for the discussion of anticipatory competence in particular, and situational assessments of traffic in general as supportive in nature. The detection of important visual cues is a necessary, but not sufficient, requirement for anticipation, and cannot, for example, be used to identify instances of passive anticipation. One potential way to identify passive anticipation may be detailed analysis of reaction times: in a larger sample, reaction times of all participants reacting only post-event could be the input for a cluster analysis. It appears likely that anticipatory drivers who consciously decide against proactive action would still exhibit a faster reaction time than reactive drivers due to their expectation of a particular conflict. Such an approach would have to control for potential factors influencing reaction times, such as age and urgency effects (Warshawsky-Livne and Shinar, 2002) as well as the severity of potential distractions (Strayer et al., 2013), which have been shown to influence a driver's ability to anticipate (He and Donmez, 2018). Nonetheless, the use of reaction times appears to be a promising approach to differentiate aggressive drivers – in this context, drivers who correctly anticipate roadway cues while consciously choosing to not act upon this anticipation pre-event – from drivers who are unaware of an upcoming conflict until it manifests.

We have also found that driver experience has a significant effect on number of pre-event actions, the variable indicating anticipatory competence. This suggests that the ability to assess traffic situations and predict their development is dependent on driver experience. These findings confirm prior research in which we investigated the effects of driver experience on anticipatory competence (Stahl et al., 2014). Further, driver experience appears to have similar effects on glance patterns towards cues as anticipatory competence. Experienced drivers looked at the cues more often, suggesting a more targeted visual search that is led by the understanding of the importance of specific elements in a traffic scenario. Experienced drivers' glances to those cues on average were also longer than those of novice drivers, and experienced drivers spent a longer time in total monitoring the cues. These findings suggest that the importance of the cues was recognized, and that they were being monitored consciously. These results are in line with the finding that with respect to hazard perception, experienced and trained drivers generally outperform novice, untrained drivers due to differences in visual search and the interpretation of the situation at hand (Garay-Vega and Fisher, 2005; Jackson et al., 2009). They further support the finding that experienced, older drivers attend to areas of the traffic scenario that indicate risks (Pradhan et al., 2005) and extend this observation by showing that experienced drivers focus their visual attention specifically on relevant visual cues that are crucial for the understanding of the traffic situation at hand.

Finally, it is important to note that not all experienced drivers displayed anticipatory actions. While this may be explained in part by instances of passive anticipation, it also stands to reason that driving experience alone does not guarantee anticipatory competency, or the ability to monitor traffic effectively and interpret it correctly. This thesis is supported by the fact that experienced drivers who exhibited pre-event actions appeared to have superior visual scanning abilities not just in comparison to novice drivers, but also in comparison to experienced drivers without pre-event actions. One differentiator for experienced, successful driver appears to be an effective visual scanning strategy. If these scanning strategies can be formalized, then interventions can be developed to aid drivers while on the road and educate drivers appropriately. For example, in Stahl et al. (2016), we showed that in-vehicle displays that highlight relevant visual cues can help novice drivers exhibit more pre-event actions. However, further research is needed to investigate whether the positive results that were found are due to actual improvements in visual scanning strategies or are simply due to the displayed information being perceived as a warning of an upcoming conflict.

5. Conclusion

This paper confirms prior findings that visual search differs significantly between novice and experienced drivers. It extends this knowledge by showing support for how experienced drivers glance both more frequently and for longer towards cues that are relevant for the correct interpretation of the given traffic situation. It also shows that anticipatory drivers, as indicated by the number of pre-event actions taken prior to conflict, attended to these relevant visual cues more. The glance patterns of those anticipatory drivers differ from non-anticipatory ones in similar fashion to the effects of experience: more frequent and longer glances were evident for drivers exhibiting pre-event actions. The research described in this paper therefore makes a case not just for general differences in glance patterns between skilled and novice drivers, but seeks to attach these differences to the recognition of meaningful cues in the context of a specific scenario. As such, it makes a case for the investigation of driver behaviour relative to particular, clearly defined traffic scenarios. This research was undertaken in a limited number of constructed simulator scenarios, and hence does not address whether similar effects can be found on the road. However, given the promising results in this controlled environment, future research should seek to investigate anticipatory driving abilities and targeted glance patterns also on the road, in both, naturalistic and controlled studies.

Declaration of Competing Interest

The authors declare no competing financial interest.

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