Anticipation in Driving: The Role of Experience in the Efficacy of Pre-event Conflict Cues

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***Abstract*—Anticipation of future events is recognized to be a significant element of driver competence. Surely, guiding one's behavior through the anticipation of future traffic states provides potential gains in recognition and reaction times. However, the role of anticipation in driving has not been systematically studied. In this paper, we identify the characteristics of anticipation in driving and provide a working definition. In particular, we distinguish it from driving goals such as eco or defensive driving and define it as a high-level competence for efficient positioning of the vehicle to facilitate these goals. We also present a driving simulator study assessing the relation between driver experience and anticipation. Thirty drivers from three different experience categories (low, medium, and high) completed five scenarios, each involving several pre-event cues designed to allow the anticipation of an event. The results showed that more experienced drivers demonstrated more pre-event actions compared with less experienced drivers. While pre-event actions resulted in improved safety on certain occasions, the effects were often not significant. Future research should further investigate the mechanisms underlying anticipation, particularly how drivers make use of temporal and spatial gains obtained through the recognition of pre-event cues.**

***Index Terms*—Anticipation, driver behavior, driver experience, driving simulator, pre-event cues.**

I. Introduction

DRIVING is a challenging task that demands the coordination of motor, perceptual, and cognitive skills. Cognition comes into play as drivers interpret perceived information and select an action. In unfamiliar situations, drivers tend to react to events, while upon encountering familiar situations, they tend to anticipate what is about to happen [1]. Being in a reactionary mode requires a given event to have occurred, thereby limiting the time a driver has to deal with the event. In contrast, anticipation of the event allows for additional space and time to reduce disruptions and avoid potential conflicts.

Facilitating a shift from reactionary to anticipatory driving may help improve safety, traffic flow, and driving economy. Studies investigating the effect of response priming on driving performance consistently report better performance if drivers have correct expectations. For example, a simulator experiment investigating response priming on a follow-up lane change request found enhanced reaction times and steering precision with valid primes [2]. Studies that have investigated reaction times of car drivers and motorcycle riders in the real world came to similar conclusions: Reaction time improves when participants are alerted and, consequently, expect an obstacle in their path [3]–[5]. The alignment between the expectation of a specific event and the actual event proves crucial for good performance. Interpreting anticipation as another form of expectation, driving performance can, therefore, be improved by enabling correct anticipation of upcoming events.

The importance of anticipation arises frequently in driving research. "The inability to predict ahead of time the risks that will appear in the roadway" is a primary cause of fatalities for novice drivers [6, p. 447]. Furthermore, in a study focusing on hazard recognition in video-recorded scenarios, experienced drivers were found to be more successful in anticipating conflicts that were about to arise than were novice drivers [7].

Attention has also been argued to interact with the ability to anticipate in the driving domain, in the sense that high workload would lead to reduced cognitive resources, thereby hindering the anticipation of emergent problems and hazard perception. Research investigating the eye fixations of novice and experienced drivers on different road types found systematically different visual scanning patterns between novice and experienced drivers [8]. With experienced drivers showcasing different scanning patterns that are more sensitive to road type, visual attention may be argued to be one of the factors enabling better hazard perception (as indicated earlier), as well as anticipation of future traffic events altogether.

Situation awareness (SA) relates to anticipation as well. In terms of Endsley's description of SA [9], anticipation would be situated on the third level, "projection of future status." This third level is described as requiring complex reasoning and significant cognitive resources, making it reasonable to assume that novice drivers will be less likely to use anticipatory competence because of the lack of experience and spare cognitive resources needed to successfully predict future system states.

Anticipation also plays a role in the theoretical conceptualization of driver behavior. In Fuller's risk avoidance model, which analyzes typical driver behavior in dealing with potentially dangerous situations, a given discriminative stimulus is suggested to have two potential consequences: 1) failure to act on the stimulus; and 2) an anticipatory avoidance response to eliminate the potential danger. If the driver fails to anticipate, then a conflict (indicated by an aversive stimulus) may develop, which will force her to either react adequately or crash [10]. Here, the "integration of features projected into the future" [10, p. 1147] is highlighted to be a desirable behavior with respect to safety.

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Tanida and Poeppel [1] also identify anticipation as a central concept in driver behavior. They describe driving as a task that is dominated by anticipatory brain mechanisms that deal with familiar stimuli. The authors suggest that these programs are only interrupted when the driver is presented with unfamiliar stimuli, in which case driver behavior becomes reactionary.

Anticipation is also found in models describing the dynamics of traffic and of driver assistance systems. In their traffic flow model, Kesting and Treiber [11] include drivers' anticipation of acceleration patterns of vehicles ahead. Onken [12], on the other hand, looks at how drivers react in particular situations as a way of guiding the development of automated systems. He theorizes about the necessity of knowing how to react in a specific situation and distinguishes between situations that are familiar and unfamiliar to drivers. He suggests that high-level knowledge-based behavior can guide decision making in unfamiliar situations, but talks about skill- and rule-based behaviors guiding responses in familiar situations. According to Onken, familiar situations are usually "anticipated through expectations" [12, p. 53].

While there is little argument about the importance of anticipation in driving, there is little research systematically investigating it. Anticipation connects a number of human factors discourses, yet no single framework captures its entirety. In this paper, we investigate anticipation from a theoretical perspective and suggest a working definition. We then report the findings from an experiment designed to 1) identify anticipation and 2) investigate the relation between experience and anticipation.

II. Definition of Anticipation in Driving

At first glance, anticipation in driving appears to be a relatively straightforward concept. An anticipatory driver would identify cues that indicate a potential conflict in advance. She would consequently be able to act to avoid conflict. However, it is surprisingly difficult to distinguish driver reactions to events from actions taken before the event. To explain the challenges, consider the scenario illustrated in Fig. 1.

Here, the traveling direction of all vehicles is from the bottom toward the top of the graphic, and we consider the perspective of the dark car, car A, which is in the left lane and traveling at the highest speed. At time t_0, the light car, car B, is traveling in the right lane, ahead of car A and at a slightly lower speed. The slowest vehicle is a truck traveling in the right lane, ahead of both cars. In this scenario, a potential conflict may occur if car B was to change lanes to overtake the truck. This conflict is visualized at time t_1; car B is signaling left and is in the process of pulling into the left lane, thereby cutting off car A. Depending on the speed difference and the distance between the two cars, car A would have to brake to avoid a collision, as visualized at time t_2.

The driver of car A might anticipate car B changing lanes and may, therefore, take action to avoid potential conflict. A defensive anticipatory driver would be likely to release the gas pedal, whereas an aggressive anticipatory driver may accelerate to pass car B before it changes lanes. In both cases, an anticipatory action is taken—the driver of car A predicts what might

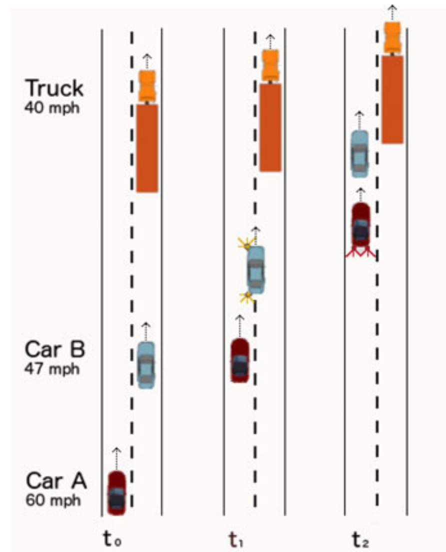

Fig. 1. Anticipatory Scenario: A potential headway conflict for the driver of car A, caused by the lane change of a lead car that attempts to overtake a truck in its own lane.

happen in the future and reacts with an anticipatory avoidance response appropriate to the driver's goal. With slight variations of the scenario, however, the determination of whether or not anticipatory competence is present becomes significantly more complex. Potential challenges include:

1) *The nonreactive, anticipatory driver:* There is a possibility for a driver to anticipate the potential conflict, but to consciously decide against taking action. While such a driver may still be considered under the "anticipatory" label (or a subcategory of such), the decision against taking action would make it difficult to distinguish this driver from a nonanticipatory one.
2) *The timing of the anticipatory action:* At what point in time does an action cease to be anticipatory, and instead become a reaction? To be recognized as an anticipatory action, does action have to be taken before car B signals a lane change or before it initiates one?
3) *The reactivity in anticipation:* Even the anticipation of events can be described as a reaction to specific cues. An anticipatory driver could be considered to be reacting not to the event itself, but to subtle cues heralding the event. For example, an increase in the acceleration of car B relative to the acceleration of the truck ahead might be considered an event to which the driver reacts.

The aforementioned example lays out the challenges in defining anticipation in driving. However, there are aspects of anticipation that can be more clearly identified:

1) Anticipation in driving needs to describe a high-level competence of cognitive reasoning that facilitates driver goals. Anticipation will increase the useful time and space in which the driver can act, but it will not determine specific actions. The driver will select a behavior to achieve his goal depending on his personal situation and characteristics. Consequently, a race car driver may use anticipatory competence to select manoeuvers to overtake the driver

ahead, while a freight trucker would likely position his truck to minimize braking or acceleration. In both cases, the competence to anticipate the traffic situation a few seconds ahead aids the drivers in achieving their particular goal—two very different behaviors, but both the result of anticipation. Following this rationale, the extent to which anticipation will help achieve short travelling times, improved safety, or fuel efficiency, will vary not just because one driver may be able to act early due to anticipation while another only reacts to highly salient events, but also because drivers may have different motivations and goals. Therefore, anticipation in driving can be described as a competence of cognitive reasoning that, based on the conscious processing of specific cues in the environment, allows the projection of future traffic states. This reasoning process is then followed up with observable, goal-directed behavior that may vary from driver to driver.

2) Anticipation requires stereotypical situations as a basis. It is not clairvoyance, but requires the recognition of cues that are indicative of distinct traffic configurations and predictive of upcoming conflicts. Anticipation therefore does not require the computation of an infinite number of potential scenarios, but the recognition of stereotypical traffic situations that have a high likelihood of resulting in similar events from one time to another [13].
3) With respect to levels of driver behavior—strategic, tactical, and operational [14], [15]—anticipation has to take place on a tactical level. Anticipation allows for the recognition of events a couple of seconds ahead. The further ahead the event to be anticipated, the more potential alternatives and the more cognitive processing is required. While the strategic level allows for general planning of driving, it does not allow for anticipation of specific events due to near endless possibilities. In contrast, sudden events do not leave enough time for the perception and cognitive processing of complex cues indicative of upcoming scenarios. Thus, on the operational level, a driver can only be described as reactive.
4) Anticipation in driving has to describe the competence of correctly interpreting cues for upcoming events, as opposed to a competence to recognize particular events. The difference between reactionary and anticipatory action (the third challenge identified earlier) has to be found in the semiotic status of the observed information. If it is a highly salient well-defined symbol for a conflict, such as the signals or brake lights of another car, then a driver is merely reacting. Little cognitive effort is necessary here. If, however, the driver picks up on relatively subtle potentially ambiguous cues, such as changes in headway distance between other traffic participants, and connects several of these cues together, then he is going beyond reaction to a well-defined symbol. Experience and significant cognitive processing are necessary to make sense of these combined cues—the driver is anticipating.

Building on these requirements, we propose the following definition of anticipation in driving: Anticipation in driving is 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.

TABLE I
THREE LEVELS OF DRIVER EXPERIENCE INVESTIGATED IN THE EXPERIMENT

Experience level	Years of licensure	Distance driven within past 12 months (km/year)	n	Mean age (SD)
Low	≤ 2	$< 10\,000$	10	19.3 (1.34)
Medium	≥ 10	$< 10\,000$	10	32.6 (9.46)
High	≥ 10	$> 50\,000$	10	29.8 (4.29)

III. Empirical Investigation of Anticipation: Method

Driving experience plays a significant role in the successful interpretation of traffic situations, specifically with regard to hazard detection [6], [7]. This fact suggests a similar heightened skill for the correct interpretation of traffic elements with respect to their meaning for the near future. We, therefore, conducted a driving simulator experiment to investigate the relation between driver experience and anticipation. Experienced drivers are expected to be more competent at anticipating upcoming events than novice drivers because of increased cognitive capacity for, and more experience with, the interpretation of surrounding traffic.

We have previously theorized that anticipation in driving is possible not only in terms of predicting actions of other traffic participants, but also with respect to the natural environment and the road environment/infrastructure [16]. Adaption of driving style because of changes in weather condition, for example, can be viewed as acts of anticipation as well. For the purpose of this research, however, we limit the scope to the anticipation of actions of other traffic participants.

A. Experimental Design

Driver experience, a between-subject variable, was the only independent variable in this experiment. Three levels of driver experience were defined (see Table I) based on years of licensure (years a valid driver's license had been held) and mileage (distance driven within the previous 12 months), similar to Holland *et al.* [17], who measured experience based on number of months since licensure and number of hours driven per week. Drivers who fell into the category of high mileage and short licensure were excluded from the experiment because of the infrequent occurrence of such people in the general population. Furthermore, the thresholds used to separate the groups were intentionally set far apart (e.g., ≤ 2 years versus ≥ 10 years of licensure) to recruit drivers with distinct differences in experience level. Our hypothesis was that drivers who had been licensed for longer periods of time (medium and high levels) would exhibit anticipatory actions at a higher rate than novice drivers. Furthermore, among the drivers who had been licensed for a longer period (≥10 years), we hypothesized that those with higher annual mileage would exhibit more anticipatory actions than low mileage drivers. Thus, we tried to recruit participants such that a large difference in annual mileage was evident between the medium and high experience groups (i.e., <10000 versus >50000 km/year). Each participant experienced five driving scenarios, which were designed to allow for anticipation of an upcoming event. The scenarios were presented in the same order for all participants as we did not intend to compare the scenarios but rather the experience groups to each other.

B. Participants

Thirty participants completed the experiment. All participants held at least a valid G2-level driver license in the province of Ontario, had driven a passenger vehicle with an automatic transmission, and reported only using their right foot to operate the accelerator and brake pedals. Of these 30 participants, ten were novice drivers with two years of licensure or less who reported driving less than 10000 km/year; ten were mid-experience drivers with ten or more years of licensure who reported driving less than 10000 km/year, and ten were highly experienced drivers with ten or more years of licensure who reported driving more than 50000 km/year. The mean ages and standard deviations (SD) for these three groups are provided in Table I. An analysis of variance followed by post hoc t-tests showed that novice drivers were significantly younger than the medium ($t(27) = -4.92$, $p < 0.0001$) and high experience groups ($t(27) = -3.88$, $p = 0.0006$). There was no age difference between the medium and high experience groups ($p > 0.05$). Overall, nine participants were female (mean age 25 years) and 21 participants were male (mean age 28 years). An independent t-test revealed that age was not statistically different between the two genders ($p > 0.05$). The female participants were fairly evenly distributed across the three experience categories (four in low, three in medium, and two in high).

Participants were recruited from the student body of the University of Toronto, as well as through calls for participation on advertisement websites, social media, and networking services. They filled out an online screening questionnaire to determine their experience category. Furthermore, they were screened for their profession and were limited to noncommercial drivers of passenger vehicles; groups with special driver training, such as cab drivers and law enforcement were excluded, as were commercial drivers of trucks and buses. The participants were also screened for simulator sickness [18]. Participants were compensated C$20 for their participation in the study. The study took approximately 1.5 h.

C. Simulator

The simulator used for this research is a PC-based, quarter-cab NADS MiniSim research driving simulator (see Fig. 2). It uses three 42-in plasma TVs to create one combined display spanning a 130° horizontal and 24° vertical field of view at a 48-in viewing distance. An additional 19-in screen is integrated

Fig. 2. NADS MiniSim driving simulator.

into the dash and displays speedometer and revolution meter. The simulator uses an authentic Chevrolet steering wheel, column gear selector, pedals, and vehicle seat. Stereo sound of the vehicle and its surroundings is portrayed through two speakers in the front; a third speaker mounted below the driver seat simulates roadway vibrations. The simulator collects a large number of driver performance measures at 60 Hz and is equipped with a four-channel video capture system. Our experiment used three cameras to capture participants' pedal positions, a frontal view of them driving, and a rear view capturing the participant and the simulator screen.

D. Driving Scenarios

Each participant experienced five scenarios. They were instructed to follow two default behaviors: 1) when traveling on the highway and not otherwise hindered (for example, by lead vehicles with slower speeds), participants were instructed to maintain their speed around the limit of 60 mi/h[1]; 2) when there was a lead vehicle, they were asked to follow the vehicle but were told that they could maintain a distance that was comfortable for them.

The five scenarios were split into two drives to give participants a break during the experiment, with scenarios 1–3 presented in drive 1 and scenarios 4–5 presented in drive 2. These five scenarios are described next. The determination of when an event started was scenario dependent but was consistent across participants. The beginning of an event was always marked by an action of a lead or overtaking vehicle that indicated a change in its speed and/or heading that would conflict with the participant. This action had to be familiar and unambiguously indicate the upcoming conflict, for example, a directional signal. In contrast, cues were ambiguous—they could, but did not necessarily result in a conflict.

[1]The simulator used in this study used a mixture of metric and imperial units. Since the strict use of metric units would have required substantial changes within the programing of the simulator, we opted to display speed in mi/h throughout.

1) Chain-Braking due to a Slow Tractor: The participant was asked to follow a chain of five passenger vehicles traveling at 40 mi/h into a curve on a two-lane rural road, with opposing traffic. Because of a green tractor traveling at 20 mi/h, initially 300 m ahead of the first car (at an approximate visual angle, VA, of 0.72°), the vehicles started to brake consecutively (first car when within 70 m from the tractor and at a deceleration of 1 m/s^2, second car when within 21 m of the first car at 2 m/s^2, third car when within 24 m of the second car at 2.5 m/s^2, fourth car when within 21 m of the third car at 2.5 m/s^2, and the last car when within 37 m of the fourth car at 2.5 m/s^2), requiring the participant to reduce speed as well. Anticipatory cues for the event were the appearance of the slow tractor in the visual scene and then the braking of each consecutive vehicle in the chain. All vehicles had to slow down from 40 to 20 mi/h, so that aside from their brake lights, the visible deceleration and diminishing headway distances between them were further cues. The defined event in this scenario was the braking of the vehicle directly ahead of the participant. If the participant had not acted on any of the cues until this point, she had to act at this point to avoid collision.

2) Vehicle Behind Cutting In-Front: After scenario 1, the participant kept on following the chain of five vehicles. Upon reaching a long straight on the two-lane rural road, the vehicles accelerated consecutively from 30 to 50 mi/h at a rate of 0.25 m/s^2. A vehicle directly behind the participant signaled for 3 s, pulled into the opposing lane, and accelerated to 125% of the participant's speed to overtake the participant's vehicle. Because of an oncoming vehicle in the opposing lane, the overtaking vehicle cut in front of the participant vehicle abruptly, after having used its right signal for 2 s and while decelerating to 40 mi/h at a rate of 5 m/s^2. In this scenario, the event was marked by the overtaking vehicle putting its right signal on. Anticipatory cues were the vehicles signaling left and pulling out of the lane, which were observable to the participant in the rear- and side-view mirrors. A second cue hinting at a potentially abrupt take over was the vehicle approaching from the opposing lane. While the mere switch into the opposing lane does not necessarily indicate the intention to merge back in front of the participant's vehicle (the overtaking driver could potentially overtake several vehicles), the oncoming traffic necessitated a merge back, and the onset of the right signal conveyed the intention to do so. The event for this scenario was the overtaking vehicle's right signal, indicating the intention to merge back into the right lane.

3) Stranded Truck on Highway Shoulder: Before this scenario, the participant merged onto a four-lane divided highway following a stream of vehicles (which maintained 55 mi/h) in the rightmost lane. A stranded truck on the highway shoulder, as well as two police cars parked on the shoulder behind the truck (without flashing lights, due to simulator limitations) were visible from a distance of 500 m (VA $\sim$ 0.48°). Upon approaching the vehicles on the shoulder, the vehicles in front of the participant started merging left (all of them using their signals for 2 s before starting the lateral movement) to safely pass the vehicles on the shoulder, thereby resulting in a chain of braking events on both the left and right 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 cues were the stranded truck and police cars, the consecutive merging of vehicles into the left lane, as well as the brake lights and decreasing speeds of vehicles ahead. Similar to scenario 1, we defined the event based on the behavior of the vehicle immediately in front of the participant vehicle. Due to the complexity of this scenario, two events were identified: 1) the braking of the lead vehicle in response to the slowing speeds of the vehicles ahead; and 2) the left signal onset of the lead vehicle indicating a merge to the left lane. This allowed for the extraction of two potentially anticipatory actions. For example, a driver changing lanes before either of these events would exhibit an anticipatory action, whereas pedal release had to take place before event 1 to indicate an anticipatory action.

4) Merging Onto a Highway: The participant followed a lead vehicle (going at 50 mi/h) onto a highway ramp. The lead vehicle failed to signal when going onto the ramp, decelerated to a relatively low speed (to 30 mi/h at 1.5 m/s^2) at the beginning of the ramp, and then varied speed, switching between acceleration (to 40 mi/h at 1 m/s^2) and deceleration without braking (to 35 mi/h at 1 m/s^2). Upon approaching the acceleration lane on the highway, the lead vehicle finally accelerated to 45 mi/h at 1 m/s^2, only to abort the merge in the middle of the acceleration lane and brake to 20 mi/h at a rate of 5 m/s^2 to let a chain of semitrailer trucks on the highway pass before merging. The event was defined as the braking of the lead vehicle in the acceleration lane. Pre-Event cues were the lack of signaling and erratic behavior of the lead vehicle, as well as the visibly busy highway. While not a necessary consequence of the cues leading up to the event, the erratic behavior described previously combined with the small gaps between the trucks on the highway made a braking maneuver likely.

5) Slow Moving Traffic on the Highway: This scenario appeared in Section I and is visualized in Fig. 1. The participant was driving on a four-lane divided highway with no lead vehicle ahead (and thus was instructed to maintain 60 mi/h). The participant then approached two vehicles in the right lane—one vehicle directly ahead and traveling at 80% of the participant's speed (first visible at VA $\sim$ 0.24°) and a semitrailer truck ahead of this vehicle traveling at 66% of the participant's speed (first visible at VA $\sim$ 0.48°). Once the distance to the vehicle ahead fell below 122 m, the speed of the truck was set to 40 mi/h, and the speed of the vehicle ahead was set to 47 mi/h. Thus, the lead vehicle was approaching the truck as the participant approached both vehicles. The lead vehicle signaled for 2 s and then pulled out into the left lane (accelerating to 50 mi/h at a rate of 2 m/s^2) to overtake the truck as soon as the participant vehicle was within 76 m of the lead vehicle. We defined the event as the signaling of the lead vehicle, which was followed by the lead vehicle overtaking the truck. The anticipatory cue was the diminishing headway between the car and the truck. The diminishing headway between the vehicle and the truck had to necessarily result in the lead vehicle either decelerating or changing lanes. The left-turn signal indicated the intention to change lanes.

E. Procedures

Participants were first verbally briefed on the experiment by the investigator. The general intent to study driving behavior was stated, and the low risk of simulator sickness was mentioned. Participants were then instructed to read the more detailed informed consent form and were given the opportunity to ask any questions not answered therein. Participants were not informed about the experimental focus on anticipation until after they completed the driving scenarios.

The investigator allowed the participants to adjust the steering wheel, backrest, and seat positions to their liking, and explained the controls of the simulator. Participants read another document with detailed instructions for the scenarios, and the investigator then engaged them in a short conversation to ensure understanding of the two default behaviors presented in the previous section.

Participants then had the opportunity to familiarize themselves with the simulator and train for the above default behaviors in two practice runs. The first run gave them an opportunity to drive on a rural road below 40 mi/h and follow a lead vehicle, while the second run involved a highway merge as well as practice at maintaining a highway speed of approximately 60 mi/h. The practice sessions took approximately 10 min in total and ended when the participant and the experimenter were both content with the performance achieved. An optional 5-min pause was then followed by the two experimental drives of approximately 10 min each. The final part of the experiment was a review session in which the investigator replayed the two experimental runs to the participant from the recorded data stream and guided the participant through a questionnaire. The intention was to get subjective feedback regarding the extent to which cues for the events were recognized and correctly interpreted. We further collected data on perceived mental effort using a 0–150 scale as suggested by Zijlstra [19], and assessed risk using the 1–10 riskiness scale used by Tsimhoni *et al.* [20].

IV. Empirical Investigation of Anticipation: Results

The data analyzed consisted of 30 responses each for the first four scenarios and 26 responses for the fifth scenario. Data for the last scenario were lost in two cases because of technical difficulties with the simulator, and in two cases due to participants dropping significantly below the prescribed speed resulting in a failed scenario. All data were reduced and coded by the first author, who was not blind to the experimental conditions. Care was taken, however, to reduce and code all simulator data before the experimental condition data (i.e., driving experience) were added.

A. Pre-Event and Post-event Actions

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. We assume that if a participant acted between pre-event cues and the event itself, then she was anticipating the upcoming event and displayed anticipatory driving competence.[2]

TABLE II
Distribution of Pre- and Post-event Actions Across Scenarios

Scenario	# of participants acting pre-event	# of participants acting post-event	Total
1: Chain braking due to slow tractor	5	25	30
2: Vehicle behind cutting in-front	5	25	30
3: Stranded truck on highway shoulder	13	17	30
4: Merging onto a highway	6	24	30
5: Slow moving traffic on the highway	7	19	26

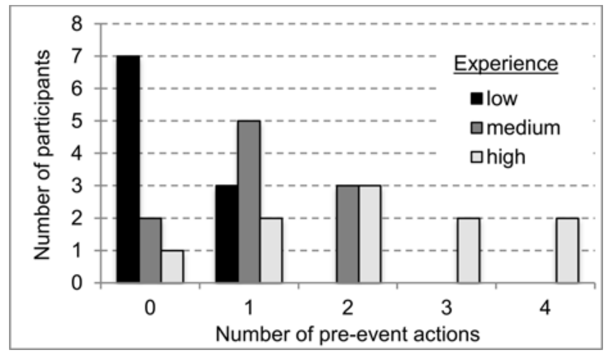

Fig. 3. Number of participants who displayed different numbers of pre-event actions (maximum possible was five) broken down by driver experience.

Since all scenarios resulted in decreased headway distances between the participant and the driver ahead, deceleration (either by release of the accelerator or depression of the brake pedal) was considered as a potential action that could be taken by the participant. Furthermore, for scenario 3 (stranded truck on highway shoulder), a lane change into the left lane was also considered to be a potential action. In fact, it was the appropriate action to take. In scenario 5 (slow moving traffic on the highway), acceleration and overtaking of the lead vehicle before it changed lanes to the left was considered to be an appropriate alternative action to deceleration.

Table II presents the number of participants grouped into pre-event and post-event action categories for each scenario. A further discussion of these specific actions is provided later in this section. With the exception of scenario 3, which provided two distinct events, the percentage of pre-event actions appear to be comparable across scenarios.

To investigate the hypothesis that experienced drivers would have higher anticipatory competencies, we compared the number of pre-event actions taken by each driver across the three experience levels (low, medium, high) (see Fig. 3). A driver could exhibit between zero and five pre-event actions (one per

[2]Participant actions were coded consistently across scenarios, e.g., the threshold brake pedal force used to define a braking action was the same for all scenarios. We were, however, sensitive to the possibility of actions being taken not as a response to pre-event cues, but for other reasons (such as regulation of headway), and therefore looked at the speed-, braking-, acceleration-, and headway profiles of participants prior to judging them as having taken pre-event actions.

scenario). No participant exhibited pre-event actions for all events. A cumulative logit model was built on these data to assess the relation of experience and number of pre-event actions. Because the number of participants with three or more pre-event actions was relatively low, we used only three categories—no, one, and two or more pre-event actions. The model was fitted using PROC GENMOD in SAS 9.1, with the specifications of cumulative logit link function and multinomial distribution. Overall, experience had a significant effect ($\chi^2(2) = 11.90$, $p = 0.003$). Participants with high experience acted prior to an event more often than participants with low experience ($\chi^2(1) = 11.79$, $p = 0.0006$), as did participants with medium experience ($\chi^2(1) = 5.47, p = 0.02$). There was only a marginal effect between high and medium experience groups, with a trend of high experience participants displaying more pre-event actions ($\chi^2(1) = 2.89, p = 0.09$). The effects of gender proved to be nonsignificant.

The following sections report the differences in overall outcome measures between the two groups of drivers (pre-event and post-event responders) for each scenario. The first measure of interest was the minimum time to collision (min TTC, as calculated based on gap distance and relative speed) recorded throughout a scenario. The second was the difference between two headway time values: maximum headway time recorded from the first cue presentation to the event minus the headway time when the event occurred. A positive difference indicated a participant closing in on the lead vehicle. The higher the difference, the more loss of headway time had taken place. We expected safety-conscious pre-event responders to have small positive differences, or even negative differences because of having increased headway time in response to a correctly interpreted cue, and likewise demonstrate higher min TTC values. On the other hand, we have discussed before that anticipation will likely aid in the realization of drivers' individual goals and, therefore, will not have a generalizable safety impact. For example, drivers could use anticipation to drive in a fuel-efficient manner, braking as little as possible and accepting dangerously low headways. We were, therefore, uncertain with respect to the overall impact of pre-event actions on the two safety measures analyzed here.

1) Scenario 1—Chain-Braking due to Slow Tractor: Five participants released the accelerator pedal before the event, i.e., the lead vehicle braking onset. Three of these five participants also braked before the event. The remaining 25 participants released the accelerator and started to brake only after the event. For the pre-event responders, the mean headway time difference was -1.88 s (SD = 1.95), and the mean min TTC was 10.1 s (SD = 2.90) (see Fig. 4). For the post-event responders, the mean headway time difference was -1.34 s (SD = 3.69 s), and the mean min TTC was 7.4 s (SD = 2.90). Overall, there was no significant difference between the two groups for headway time difference ($p > 0.05$). Min TTC was marginally significant ($t(28) = -1.89$, $p = 0.07$). Although we expected to see positive headway differences in general, the majority of responses was negative. This unexpected finding might be due to participants responding to an upcoming curve in the driving environment.

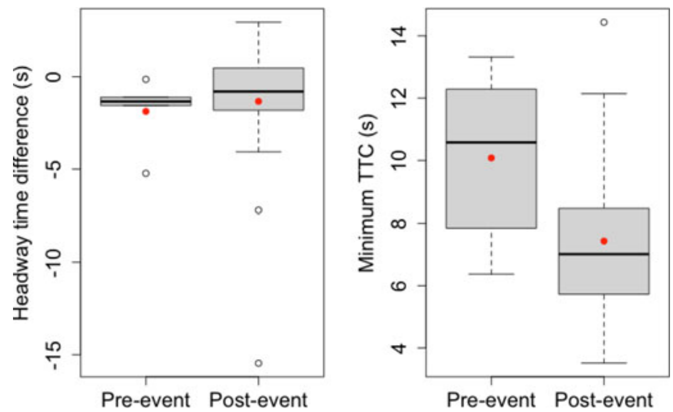

Fig. 4. Headway time difference and min TTC for Scenario 1 (in this and all following boxplots we present minimum, first quartile, median, third quartile, and maximum, as well as potential outliers indicated with hollow circles and means indicated with solid circles).

2) Scenario 2—Vehicle Behind Cutting In-Front: Five participants released the accelerator before the overtaking vehicle signaled its merge back into their lane. In addition to releasing the accelerator pre-event, one participant also braked pre-event, three braked post-event, and one did not brake at all.

The remaining 25 participants did not show clear pre-event actions. One of these participants remained entirely passive throughout the scenario and did not release the accelerator or brake even when the overtaking vehicle merged back into his lane, leading to a minimum TTC value of 2.9 s. Four participants released the accelerator after the vehicle signaled but did not brake, and 21 released the accelerator and also started to brake.

Since the lead car changed mid-scenario due to the overtaking manoeuver, headway time difference could not be calculated as presented earlier. For this scenario only, we focused on headway time to the lead vehicle at the time of the event, hypothesizing that anticipatory drivers would have noticed the overtaking vehicle and increased their headway in response. It should be pointed out that while in all other scenarios small headway time differences are desirable, here a large headway time is desirable. For the pre-event responders, the mean headway time at the event was 2.16 s (SD = 1.11), and the mean min TTC was 9.02 s (SD = 2.73) (see Fig. 5). For the post-event responders, the mean headway time was 1.35 s (SD = 0.73), and the mean min TTC was 11.8 s (SD = 9.27). Four min TTC values were excluded from analysis, two from pre-event and two from post-event groups, due to the values being extremely large compared with the rest of the observations (>100 s). The difference in headway time was significant ($t(28) = -2.06$, $p = 0.046$), whereas the difference in min TTC was not significant ($p > 0.05$).

3) Scenario 3—Stranded Truck on Highway Shoulder: Thirteen participants displayed pre-event actions: six released the accelerator before the vehicle directly in front braked (due to the lane change of the first car in the right lane), seven changed lanes before the vehicle directly in front did so, and two exhibited both actions. The remaining 17 participants did not

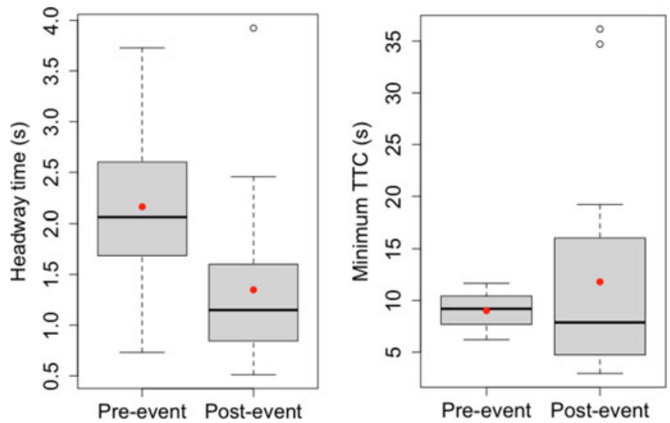

Fig. 5. Headway time and min TTC for Scenario 2.

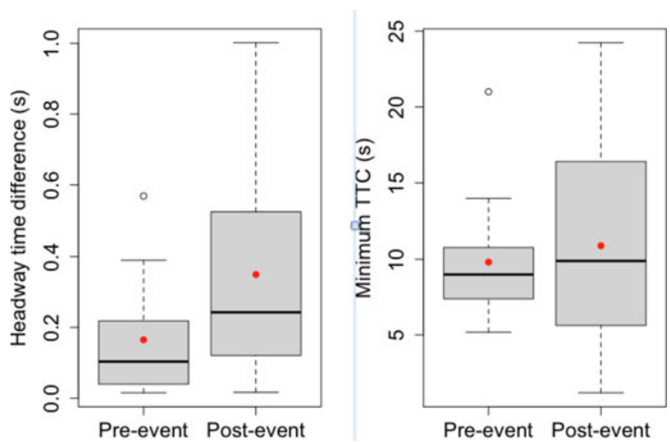

Fig. 6. Headway time difference and min TTC for Scenario 3.

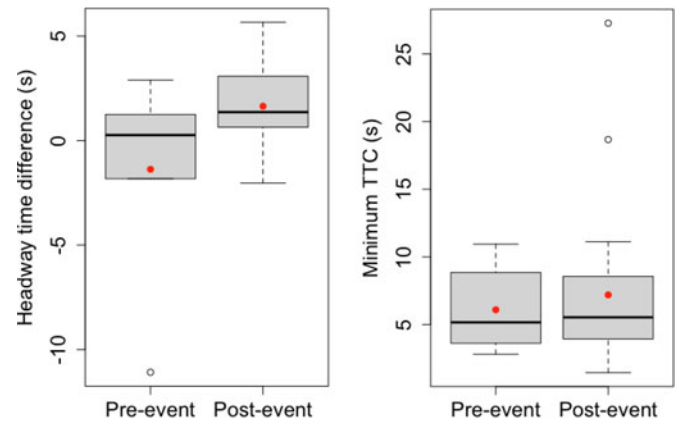

Fig. 7. Headway time difference and min TTC for Scenario 4.

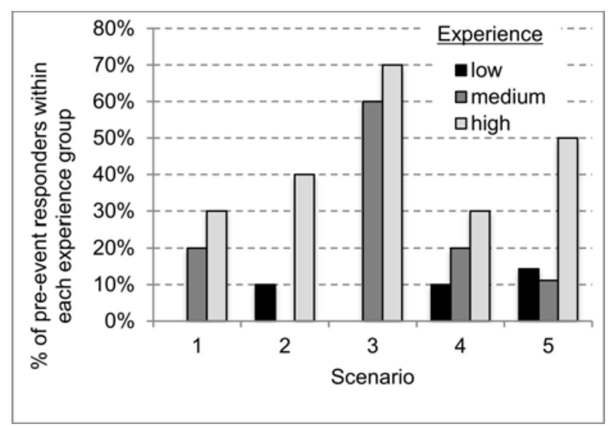

Fig. 8. Percentage of participants within each experience group who acted pre-event during a scenario.

act before the first vehicle merged left, and only released the accelerator after the convoy of cars including the vehicle directly in front had started braking. In this group, five participants did not change lanes at all throughout the scenario, and 12 merged left only after the vehicle directly in front did so. For the pre-event responders, the mean headway time difference was 0.17 s (SD = 0.17), and the mean min TTC was 9.8 s (SD = 4.2) (see Fig. 6). For the post-event responders, the mean headway time difference was 0.35 s (SD = 0.31) and the mean min TTC was 10.8 s (SD = 6.5). The effect for headway time difference was significant ($t(25.9) = 2.06$, $p = 0.049$). No significant difference was found for min TTC ($p > 0.05$).

4) Scenario 4—Merging Onto a Highway: Six participants released the accelerator before the lead vehicle started to brake in the acceleration lane (i.e., pre-event). Three of these participants also braked pre-event. The remaining 24 participants did not display pre-event actions: 22 released the accelerator only after the lead vehicle started braking and two did not release the accelerator at all. Among the post-event responders who released the accelerator pedal, eight did not use the brake. For the pre-event responders, the mean headway time difference was 1.64 s (SD = 2.0), and the mean min TTC was 7.19 s (SD = 5.64) (see Fig. 7). For the post-event responders, the mean headway time difference was −1.37 s (SD = 5.03), and the mean min TTC was 6.09 s (SD = 3.2). No significant effects were found for headway time difference ($p > 0.05$) or min TTC ($p > 0.05$).

5) Scenario 5—Slow Moving Traffic on the Highway: Seven participants displayed pre-event actions. One participant released the accelerator prior to the vehicle ahead signaling its lane change, and six participants took the opposite approach of accelerating. These six never had to release the accelerator or brake pedals within this scenario because they had already passed or were in the process of passing the other vehicle as it was signaling. The remaining 19 participants approached the vehicle and truck at approximately 60 mi/h, four of these were traveling in the left lane of the otherwise empty highway, and 15 were traveling in the right lane and switched to the left upon approaching the vehicles. These participants maintained a fairly constant speed until they braked after the vehicle ahead started signaling left. Given that a majority of pre-event responders accelerated past this vehicle, headway time difference and min TTC are not appropriate measures for this scenario.

Fig. 8 summarizes pre-event actions, grouped by driver experience, across the five scenarios. In particular, it presents the percentage of participants within each experience group who

TABLE III
SUBJECTIVE RESPONSES

Subjective measure	Mean response (SD)		
	0 pre-event actions taken	1 pre-event action taken	≥ 2 pre-event actions taken
Surprise (1 to 7)	3.94 (0.78)	3.62 (1.47)	2.74 (1.39)
Perceived risk (1 to 10)	4.36 (1.18)	4.46 (1.16)	3.76 (1.55)
Mental effort (0 to 150)	40.6 (13.1)	46.1 (14.2)	34.8 (21.3)

acted pre-event during a scenario. A statistical analysis was not conducted due to the low number of pre-event actions observed for certain scenarios. However, the statistically significant effect of experience reported previously at the aggregate level appears to be supported at the individual scenario level. In a given scenario, the percentage of pre-event responders in the high and medium experience groups tended to be larger than in the low experience group.

B. Subjective Responses

At the end of the experiment, participants reviewed their two experimental runs and responded to a series of questionnaires.

First, participants were asked if they had anticipated the event and taken preemptive action. In 30 of the 38 cases (79%) where a participant actually had taken a pre-event action, participants responded yes. In 73 of the 112 cases where a participant had not taken a pre-event action, participants also responded yes (65%).

Participants were asked to rate their levels of surprise for the events on a seven-point Likert scale (ranging from "not at all" to "very much"). Their responses were averaged across the five scenarios. These averages were then compared among three participant groups: those who had 0 pre-event actions, those who had one pre-event action, and those who had two or more pre-event actions. The mean surprise ratings appeared to decrease with increasing number of pre-event actions taken (see Table III); however, there were no statistical differences among the three groups ($p > 0.05$).

For each scenario, participants indicated their perceived risk on a ten-point scale and their perceived mental effort on a continuous scale from 0 to 150 (see Table III). There were no significant differences between the three groups of participants for either of these measures ($p > 0.05$).

V. DISCUSSION

In a driving simulator experiment, we determined that the points in time at which different drivers act on events in their environment differ significantly. A majority of drivers only react to changes in traffic that represent unambiguous conflicts. Fewer drivers identify and act on cues prior to these traffic events. The temporal gains of pre-event, anticipatory actions present a potential for improved safety—a driver recognizing changes in traffic early will always have more time and space to take appropriate action. However, improved safety is not a necessary consequence of anticipation because the individual driver decides to what end she uses this competence. For example, for the last scenario in our experiment, the majority of pre-event responders executed the more aggressive overtaking manoeuver as opposed to deceleration. Similarly, the comparisons of headway time differences and minimum TTC in scenarios 1–4 showed that, while there is a general tendency of pre-event responders to be safer, these differences were not always significant. These findings support the understanding of anticipation as a high-level cognitive competence aiding drivers in their particular driving goals. Anticipation does not connect to one specific goal or behavior universally.

The approach chosen to distinguishing between anticipation and reaction in this study relied on the use of specified events in stereotypical scenarios, and the use of cues leading up to these events. This approach proved feasible to distinguish between pre- and post-event actions. The subjective feedback provided by participants with pre-event actions, which consistently referred to the cues provided, further strengthens the understanding of anticipation as a competence of interpreting cues to identify stereotypical scenarios, and thereby future events.

Altogether, the percentage of participants who took pre-event actions was relatively low, particularly so for some of the scenarios. A potential reason is that the use of anticipation might be a relatively difficult task for most drivers, and this difficulty is mediated by the specifics of the situation. The relatively few pre-event actions observed may also be attributable to a driver anticipating correctly, but choosing not to act prior to the event. Such a driver might instead only prepare for quick reaction and pay heightened attention to possible cues. Such a phenomenon would also help explain the high number of participants who considered themselves as having taken preemptive actions without their simulator data supporting those claims. The nonreactive anticipatory driver was discussed as the first challenge in Section II. For this reason, the definition of anticipation we proposed captures both anticipation with an appropriate pre-event action, as well as anticipation that is limited to mental preparation without an observable pre-event action. This passive type of anticipation that does not result in a measurable control input to the vehicle could not be clearly identified in this experiment. Future research should, therefore, incorporate eye tracking data and a focus on reaction times. Compared with a nonanticipatory driver, we would expect the nonreactive anticipatory driver to visually fixate on cues relevant to an upcoming event longer and more frequently, and be able to react faster once the event happens.

We have also shown that experienced drivers are more likely to take pre-event actions. This result supports our initial hypothesis as well as confirms the effects of experience reported in other experiments that investigated drivers' abilities to correctly interpret traffic situations [6], [7], [21]. We realize that because of novice drivers in this study being significantly younger than more experienced drivers, as is the case in the general population, the effect of experience may also be attributed partially to age differences. In order to unambiguously determine the influence of age, years of licensure, and annual mileage, a future experiment should test different combinations of these factors. However, even though there was no age difference between medium- and high-level experience groups, there still was a marginal difference observed in their likelihood to exhibit pre-event responses. As is also evident in Fig. 3, we found counts of three and four pre-event actions per person only in the group of highly experienced drivers (two with three, and two more with four actions), while no driver with medium experience reached more than two pre-event actions. Due to the limited count frequency, however, we only accounted for participants with zero, one, and two or more pre-event actions in the cumulative logit model, which was therefore not sensitive to this difference between medium and high experience groups. A repetition of this study with a higher number of subjects is, therefore, advisable and may support the difference between medium and high experience groups.

Experienced drivers showcase a heightened competence for the identification of cues for upcoming events, as well as for their correct interpretation. This was indicated by their higher number of pre-event actions, but became even more apparent throughout the postexperiment review sessions. When asked to recollect the behavior of cars prior to an event, the majority of novice drivers only remembered the event itself (i.e., the brake lights of a lead car). Experienced drivers in contrast frequently pointed out multiple of the pre-event cues and often gave detailed explanations for how they interpreted them.

While this study showed positive effects of high mileage driving and longer years of licensure on anticipation, it can also be expected that the reduced perceptual and cognitive abilities characteristic of advanced age will eventually negate the positive effects of experience. Future research should investigate whether and when increasing age results in worsening of anticipatory competence. The ages of our drivers, in general, were relatively young. A larger study, with a wider range of age groups in addition to years of licensure and annual mileage, should be undertaken. Furthermore, when defining experience, our study only focused on annual mileage in the last year. The question of whether and to what extent the mileage driven in earlier years impacts anticipatory competence remains open.

It should also be noted that there is a possibility of pre-event actions having been taken in response to elements in the driving scene other than the pre-event cues (e.g., the upcoming curve in scenario 1). To minimize the likelihood of incorrectly attributing actions to pre-event cues, we took context into account by visually inspecting the entire response of each participant throughout the scenario and also considered subjective responses of the participants. However, for future research, several coders who are blind to the experimental conditions could be used to ensure objectivity and enable tests for interrater reliability. Furthermore, counterbalanced designs could be used, exposing participants to two sets of each scenario, one with and one without the conflicting event taking place. Both measures could serve to further strengthen the distinction between pre- and post-event actions.

Finally, the limited types and number of scenarios chosen for this study are a challenge to generalization. We investigated only the anticipation of other drivers' actions in the traffic environment, and we did so in five scenarios. Future research should continue investigating anticipation in scenarios other than those used in this research and also look at anticipation of other phenomena, such as changes in weather and road infrastructure [16].

Future research should also identify ways to facilitate anticipation. An interface could be developed that helps drivers identify and interpret important pre-event cues. For experienced drivers with an already high potential for anticipatory competence, such an interface should focus on augmenting cues to activate skill-based behavior, while novice drivers would likely profit from a rule-based approach that also aids in the interpretation of those cues [16]. Facilitating anticipation may also prove important in automation design. For example, there will necessarily be a phase when autonomous vehicles will share the road with human drivers. Understanding how competent human drivers are able to interpret traffic situations and anticipate other drivers' behavior can help designers train automation to do the same.

VI. Conclusion

In this paper, we discussed theoretical aspects of anticipation and related it to hazard perception, attention allocation, and SA. We have defined anticipation as a high-level cognitive competence for perception and interpretation of familiar cues, independent of specific driver goals that it may or may not help achieve. We conducted a simulator experiment to investigate the relationship between anticipation and driving experience. Pre-Event actions were identified primarily among experienced drivers, supporting the hypothesis that greater driving experience is associated with higher anticipatory competence. Finally, we have discussed the implications for how deeper understanding of anticipatory competence can inform interventions for conflict avoidance in driving.

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