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Supporting anticipation in driving through attentional and interpretational in-vehicle displays

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ABSTRACT

Objective: This paper evaluates two different types of in-vehicle interfaces to support anticipation in driving: one aids attention allocation and the other aids interpretation of traffic in addition to attention allocation.

Background: Anticipation is a competency that has been shown to facilitate safety and eco-driving through the efficient positioning of a vehicle for probable, upcoming changes in traffic. This competency has been shown to improve with driving experience. In an earlier simulator study, we showed that compared to novice drivers, experienced drivers exhibited a greater number of timely actions to avoid upcoming traffic conflicts. In this study, we seek to facilitate anticipation in general and for novice drivers in particular, who appear to lack the competency. We hypothesize that anticipation depends on two major steps and that it can be supported by aiding each: (1) conscious perception of relevant cues, and (2) effective processing of these cues to create a situational assessment as a basis for anticipation of future developments.

Method: We conducted a simulator experiment with 24 experienced and 24 novice drivers to evaluate two interfaces that were designed to aid the two hypothesized steps of anticipation. The attentional interface was designed to direct attention toward the most relevant cue. The interpretational interface represented several cues, and in addition to directing attention also aimed to aid sense-making of these cues.

Results: The results confirmed our hypothesis that novice drivers' anticipation performance, as measured through timely actions to avoid upcoming traffic conflicts, would be improved with either interface type. However, results contradicted our expectation that novice drivers would obtain larger improvements with the interpretational interface. Experienced drivers performed better than novice drivers to begin with and did not show any statistically significant improvements with either interface.

Conclusion: Both interfaces improved anticipation performance for novice drivers. Future research should evaluate the effectiveness of these interfaces in a wider variety of driving conditions, such as when the driver is multitasking.

1. Introduction

Anticipation has been argued to play a role in driving safety, hazard perception, and eco-driving. With respect to safety, research has shown anticipatory aids to facilitate earlier deceleration prior to conflicts (Popiv et al., 2010) and better reaction times in combination with improved, smoother deceleration profiles (Laquai et al., 2011). Response priming for specific driving tasks has been studied as well, and proven to have positive impacts both in simulator (Hofmann and Rinkenauer, 2013) and real world research (Davoodi et al., 2012; Fitch et al., 2010). Hazard perception has been connected to anticipation and described as "the ability to anticipate traffic situations" (Sagberg et al., 1997, p. 407). This ability has been argued to support safety by maximizing available decision-making time (Jackson et al., 2009). Anticipation can also be used to minimize pedal use (for both braking and accelerating), and is therefore part of hypermilers' strategies to drive more economically (Hypermiling Techniques, 2011). Research into eco-driving, conducted both in driving simulators (Baer et al., 2011; Rommerskirchen et al., 2013) and on the road (Thisjen et al., 2014), suggests that aids for the anticipation of upcoming braking events can generate fuel savings of approximately 10%.

In prior publications, we have reviewed the role of anticipation in driving research and reported anticipation to be a concept

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that has not been explicitly defined or operationalized, but that is claimed to benefit both safety and eco-driving and is considered to be crucial to skilled driver behavior (Stahl et al., 2014a). We have also discussed the theory of anticipation in driving (Stahl et al., 2014b), and 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., 2014b, p. 605). Thus, we see anticipation in driving as a competence to correctly interpret traffic situations and their development, akin to third level situation awareness (Endsley, 1995), and consider it to take place at the tactical level in Michon's hierarchical model of driving performance (Michon, 1985). 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. We have provided a detailed discussion on the theory of anticipatory driving in Stahl et al. (2014b).

In Stahl et al. (2014b), we have also reported the results of a driving simulator study that investigated anticipation in several simulator scenarios, and found that experienced drivers in general were able to anticipate, and take action to avoid upcoming conflicts, whereas novice drivers nearly completely lacked this competence. Currently, it is not well understood how we can facilitate anticipation in general and for novice drivers in particular, who appear to lack the competency. The current paper discusses differences between novice and experienced drivers with the aim of finding methods to aid anticipation. It then reports on a new simulator experiment conducted with novice and experienced drivers, in which we investigated two different types of interfaces designed to aid anticipation.

1.1. Anticipation in driving: perception and interpretation

In prior research (Stahl et al., 2014b), we found that experienced drivers were more likely to exhibit anticipatory competence and act to avoid potential conflicts. This finding was expected given our hypothesis that experienced drivers possess heightened skills for the timely and accurate interpretation of the local traffic situation. It was also in line with prior research in hazard perception, where experienced drivers exhibited superior visual scanning patterns (Garay-Vega and Fisher, 2005) and early recognition of hazards (Jackson et al., 2009). We argued before (Stahl et al., 2013) that anticipation in driving is rooted in the identification of stereotypical situations in traffic. In this sense, both anticipation and hazard perception rely on skilled perception and correct interpretation of the surrounding traffic situation. These mechanisms are learned competencies in large, and therefore are impacted positively by experience and repeated exposure to similar situations, as well as the abilities to access and compare the current situation to similar situations stored in memory.

The mechanism by which experience benefits anticipation should therefore be viewed as a top–down process in which established mental models and knowledge from relevant past experiences guide attention and the interpretation of sensory input from the traffic environment. This view of top–down processing in traffic has also been discussed by Hole (2007) and is an idea in the constructivist tradition, where learning takes place as an iterative, comparative process between perceived information and constructs of the world. Constructs are the reference point for interpretation of sensory information, and new information in turn continuously updates and changes our mental constructs.

In this regard, facilitating anticipatory competence can be seen as a matter of aiding in the development of a catalog of stereotypical traffic situations, their likely progression in the immediate future, and appropriate actions to position a vehicle efficiently in those situations. In post-experiment cognitive walkthroughs following our earlier experiment (Stahl et al., 2014b), experienced drivers who exhibited timely, anticipatory actions frequently referred to past experiences when explaining the perceived traffic scenario and their actions within it. They also presented more complete accounts of the experimental scenarios they had driven through, remembering more cues, connecting them causally, and drawing conclusions from those observations (Stahl et al., 2014a).

Experience can be argued to lead to a catalog of stereotypical situations that is more detailed and more extensive. Consequently, for the experienced driver, the process of interpreting the situation at hand is heavily guided through the knowledge of similar situations. Efficient and fast skill-based behavior (Rasmussen, 1983) takes over in this case. The novice driver in contrast may be unable to match the current situation to a fitting, memorized one due to an underdeveloped catalog of stereotypical situations. The novice driver will instead rely more heavily on inductive reasoning, such that more effortful processing will take place. He will still be able to interpret the current situation, but the accuracy of his interpretation will rely more on high level, knowledge-based behavior.

These theoretical considerations suggest two crucial steps for anticipation in driving, namely (1) the conscious perception of appropriate cues that serve as indicators for the traffic scenario at hand, and (2) efficient cognitive processing that leads to a quick and correct interpretation of these cues. Experienced drivers' superior performance with respect to anticipation can be argued to result from heightened skill in both. Their driving altogether has become a more automated procedure, so that more cognitive resources are available to monitor the environment for cues. Even more so, frequent exposure to a multitude of stereotypical traffic situations will result in knowledge of appropriate cues indicating those situations, such that the monitoring of surrounding traffic will become a more targeted process than for a novice driver. Thus, in line with Neisser's perceptual cycle model (Neisser, 1976), anticipation relies on a cyclical, continual process of cue perception and cue interpretation guided by mental models developed over time.

1.2. Aiding anticipation

While we cannot substitute for the heightened competencies of an experienced driver, we can attempt to mitigate lack of experience by highlighting relevant cues, and aiding the correct interpretation of these cues. Even for an experienced driver, highlighting appropriate cues may hold promise, since cues missed due to distraction can result in incomplete or incorrect situation assessments.

Different types of interfaces aiding anticipation have been proposed in prior driving research. Toennis et al. (2007) discussed the use of a head-up display that communicates the stopping distance to the driver by visualizing the distance that would be covered before a full stop. Further, Laquai et al. (2011) proposed and investigated the use of color-coded LED arrays to help drivers modulate their brake pedal control in response to other vehicles, under the assumption that car to car communication would be available in the future. With a particular focus on improving fuel consumption, prior research has investigated interfaces that suggest the optimal gear to the driver (Van der Voort and van Maarseveen, 1999), and present optimal coasting distances to minimize braking (Baer et al., 2011; Rommerskirchen et al., 2013). All of these examples aim to directly support vehicle control when the system is anticipating in place of the driver. Further, none of these interfaces support the anticipation of potential conflicts resulting from actions that might be taken by other traffic participants.

In order to help drivers anticipate traffic situations, we propose that the drivers can be aided in the identification and interpretation of relevant cues. Driver training is one potential means of teaching drivers these competencies. A PC-based risk awareness training using recorded, real-world traffic scenarios, for example, had positive effects on participants' performance in a subsequent simulator experiment (Fisher et al., 2002). With respect to anticipation, training can be expected to contribute to the development of a store of stereotypical situations to facilitate comparative analysis.

Another approach, which is the focus of this paper, is to use a real-time in-vehicle design solution that can aid the driver in anticipating potential conflicts as they are happening, as opposed to requiring time outside of the car (e.g., in a classroom) to develop an adequate store of stereotypical situations. To this end, we have described anticipation in driving using an information processing-based model, where successful anticipation relies on the perception of relevant cues for a given traffic situation leading to the correct interpretation of that traffic situation. Based on this model of anticipation, we propose two different in-vehicle interface types to (1) highlight relevant cues, thereby calibrating driver attention, and also (2) aid in the cognitive interpretation of those cues such that a correct mental model is built.

The *attentional* interface type focuses on calibrating attention by highlighting the most relevant cue for the understanding of the situation at hand in an attempt to ensure that drivers attend to it. This interface therefore specifically aids perception, without explicitly supporting the cognitive sense-making process to interpret the meaning of the perceived cues. The *interpretational* interface type also seeks to calibrate attention, but in addition, aids the driver in interpreting the meaning of the cues that it highlights. It would therefore be designed to guide cognitive sense-making by suggesting possible consequences of the perceived cues, and hence support both the first anticipatory stage of perception and the second stage of cognitive processing.

The driving simulator experiment described in this paper was conducted to evaluate these two types of interfaces. Our main hypothesis was that actively calibrating driver attention with appropriate interfaces would result in earlier actions on upcoming conflicts, and therefore result in more anticipatory driving behavior. We have reasoned that experienced drivers will be more competent with the correct interpretation of a given traffic situation due to the benefits of their larger catalog of stereotypical situations. Facilitating anticipatory competence for experienced drivers should therefore focus on calibrating their attention such that they attend to the relevant cues, and less on aiding in the interpretation of those cues. Novice drivers in contrast may not possess a suitable store of reference situations, such that aiding anticipatory competence should focus on both attention allocation to relevant cues and the interpretation of those cues. This rationale led us to expect novice drivers to perform better with the attentional interface than without, and better with the interpretational interface than with the attentional one. Experienced drivers were expected to generally anticipate more often than novice drivers, with smaller improvements when driving with the interfaces, and no additional gain with the interpretational interface over the attentional one.

2. Material and methods

2.1. Participants

Forty-eight participants completed the experiment. All participants held at least a valid G1-level license (allowing them to drive when accompanied by a fully licensed driver) in the province of Ontario (or equivalent), had driven a passenger vehicle with an automatic transmission, and reported only using their right feet to operate the accelerator and brake pedals. Drivers were recruited for the study based on years of licensure and annual mileage in the previous year with cutoffs detailed in Table 1. Most participants were recruited from the student body of the University of Toronto or from Young Drivers of Canada, 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

Table 2 presents the experimental design, which was a $2 \times 3 \times 3$ mixed factor design with experience (novice and experienced) and interface type (no interface, attentional interface, and interpretational interface) as between-subjects variables and experimental phase (pre-intervention, intervention, and post-intervention) as a within-subject variable. The different combinations of experience and interface type (2×3) had distinct groups of participants, with 8 participants in each group. Participants were randomly assigned to interface type, stratified according to experience. From the statistical analysis perspective, the random factor 'participant' was nested under the interaction of experience and interface type.

Driving experience had two levels defined based on years of licensure (i.e., years a valid driver's license has been held) and mileage (i.e., distance driven within the previous 12 months; Table 1). These categories were similar to the ones used in our earlier study (Stahl et al., 2014b) with the exception that the medium-experience level was merged with the high-experience level as no significant differences were observed between these two levels with respect to the number of pre-event actions taken, our measure of anticipatory action in Stahl et al. (2014b) and in the current study. 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 (in Stahl et al. (2014b), we used two and ten years, respectively).

Every participant drove the simulator through three different scenarios repeated in three experimental phases, for a total of nine drives (one scenario per drive). The first (pre-intervention) and third (post-intervention) phases involved no interfaces. In the second phase (intervention), the participants who were assigned to the attentional and interpretational interface conditions experienced the respective interfaces, whereas the participants assigned to the no interface condition were not presented with any interfaces. The 'no interface' condition was a general control group; whereas the 'pre-intervention' phase provided a baseline assessment of anticipatory competence for all participants. The 'post-intervention' phase enabled us to assess potential learning effects from the anticipatory interfaces, while the 'no interface' condition enabled us to statistically tease out general learning effects that may have occurred due to simulator acclimation and repeated exposure to driving scenarios.

2.3. Apparatus

The simulator used is a PC-based, quarter-cab NADS MiniSim research driving simulator (Fig. 1). It uses three 42″ plasma TVs to create one combined display spanning a 130° horizontal and 24° vertical field of view at a 48″ viewing distance. An additional 19″ screen integrated into the dash 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 speak-

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)
Low	≤3	<10,000	24	19.5 (2.19)
High	≥8	>50,000	24	40.2 (14.23)

Table 2
Experimental design; highlighted in grey are the scenarios in which an interface intervention was used.

		Between subjects	Phase 1:	Within subjects:completed by all participants (#1–48) Phase 2: (Scenarios 1–3)	Phase 3: (Scenarios 1–3)	(Scenarios 1–3)
Group:Participant #	n	Experience	Interface type	Pre-intervention	Intervention	Post-intervention
1: #1–8	8	Novice	No	No interface	No interface	No interface
2: #9–16	8	Experienced				
3: #17–24	8	Novice	Attentional	No interface	Attentional interface	No interface
4: #25–32	8	Experienced				
5: #33–40	8	Novice	Interpretational	No interface	Interpretational interface	No interface
6: #41–48	8	Experienced				

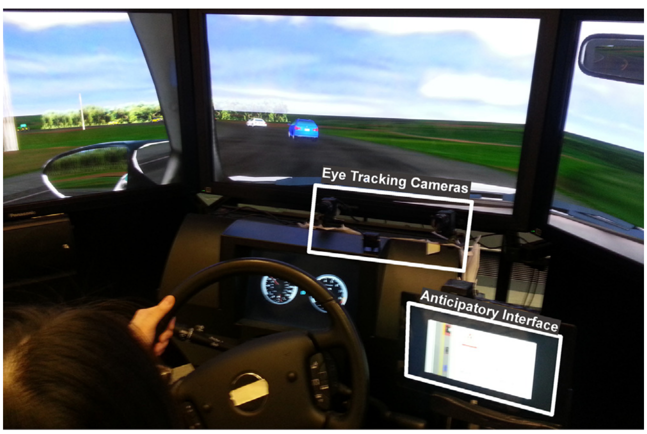

Fig. 1. NADS MiniSim driving simulator with anticipatory interface displayed on Surface Pro 2 (bottom right rectangle) and eye tracking hardware, consisting of infrared emitter and two cameras (rectangle in the middle).

ers in the front; a third speaker mounted below the driver seat simulates roadway vibrations. The simulator collects driving data 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. The anticipatory interfaces were presented through a Microsoft Surface Pro 2, which received data from the simulator in real-time. The Surface was mounted to the right of the dashboard, did not obstruct the view of other screens, and had a visible screen size of 10.6″. A dashboard mounted Seeing Machines Facelab 5.1 Eyetracker collected gaze data at 60 Hz.

2.4. Driving scenarios and displays

Each participant experienced three different driving scenarios and drove each one three times for a total of nine drives. Each drive was relatively short, with none lasting longer than five minutes. Scenarios were constructed such that participants had time to settle at the beginning, with a single event presented toward the end of a drive. The events were designed to assess whether drivers exhibited pre-event actions, which was a surrogate measure for anticipatory competence. The beginning of an event was marked by an action of a vehicle ahead of the participant resulting in a change of speed or heading that would conflict with the participant's vehicle. This action had to be familiar and unambiguously indicate the upcoming conflict, such as the onset of lead vehicle brake lights.

The scenarios were adapted from our previous experiment (Stahl et al., 2014b). Participants were instructed to (1) maintain a relatively constant speed around the speed limit of 60 mph when traveling on the highway (using the metric system in Canada, participants were informed that 60 mph is close to 100 km/h), and to (2) maintain a comfortable distance when instructed to follow a lead vehicle without overtaking. As mentioned earlier, each scenario was repeated three times; however, the scenarios were modified from one repetition to the next to minimize learning effects. Scenarios never took place in the same location in a drive, and as such, road curvature and the surrounding environment differed significantly. Colors and types of the vehicles the participant interacted with in a given scenario were also changed from one drive to the next. Finally, smaller conflicts that were not of interest to the investigation (e.g., lead vehicle braking) were introduced prior to the scenarios and these earlier conflicts varied across drives.

Scenario 1—Stranded truck on highway shoulder; repeated on drives 1, 4, and 7: For this scenario, the participant found himself 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 cues that could facilitate anticipation were the stranded truck, the consecutive merging of vehicles into the left lane, as well as the brake lights and decreasing speeds of vehicles ahead. The event was based on the behavior of the vehicle immediately in front of the participant vehicle in the right lane, which in reaction to cars braking and merging to the left lane (if they were in the right lane before) braked and merged to left itself. We therefore defined the event to be the instance when this car activated its left turn signal.

The interfaces designed for this scenario highlighted the stranded truck. While the attentional interface was limited to noti-

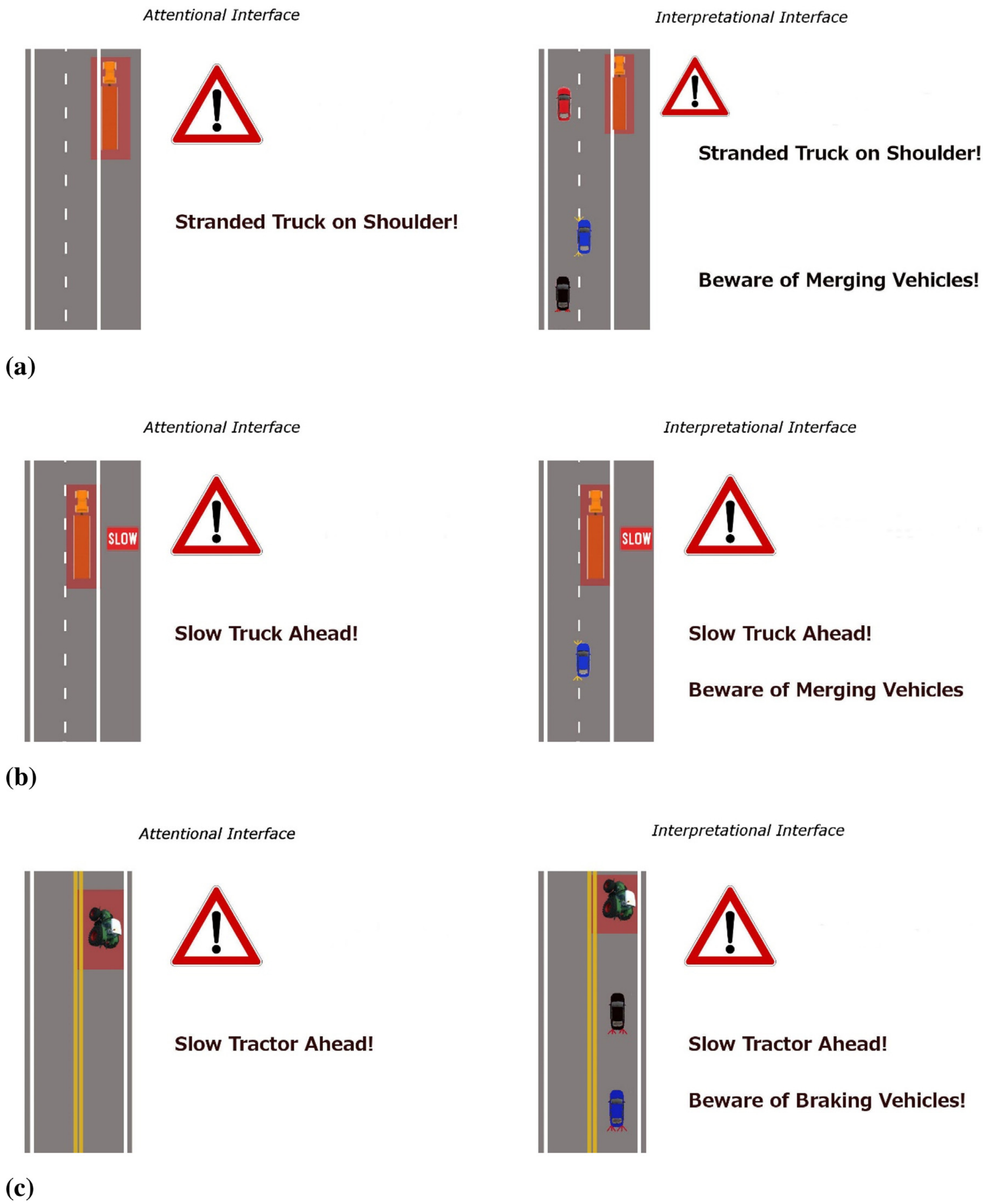

Fig. 2. Attentional (left) and interpretational (right) displays used in the experiment for the three simulator scenarios: (a) Scenario 1—stranded truck on highway shoulder, (b) Scenario 2—slow moving traffic on the highway, (c) Scenario 3—chain-braking due to a slow tractor.

fying the driver of this truck only, the interpretational interface also displayed the likely consequences of the stranded truck on the surrounding traffic (Fig. 2a). Both interfaces, attentional and interpretational, were displayed at the same point in time in the scenario, after the stranded truck was visible and prior to the participant passing the truck. In general, for all three scenarios, after the first cue became visible, the participants were given time to assess the unfolding situation before the interfaces were displayed. It should be noted that for this scenario as well as the following two, the interpretational interfaces did not provide clear instruction for action. We wanted to prevent our participants in this experiment from potentially blindly obeying suggested actions instead of debating appropriate action based on their situational understanding. The focus of this study was on interpretation rather than action selection. The interpretational interfaces we used in this experiment were predictive in nature in the sense that they presented potential consequences before these consequences materialized, but did not provide suggestions for action selection.

Scenario 2—Slow moving traffic on the highway; repeated on drives 2, 5, and 8: 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). He 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. The anticipatory cue was the diminishing headway between the vehicle and the truck. This diminishing headway had to necessarily result in the vehicle ahead either decelerating or changing lanes.

Both interfaces for this scenario focused on the slow moving truck in the right lane as the most important cue. The attentional interface showed only the slow truck and an accompanying message, whereas the interpretational interface also displayed a car behind the truck that is in the process of switching from the right to the left lane as a potential consequence of the situation (Fig. 2b). The interfaces were displayed at the same point in time prior to the slow car changing its lane.

Scenario 3—Chain-braking due to a slow tractor; repeated on drives 3, 6, and 9: The participant was asked to follow a chain of five passenger vehicles traveling at 40 mph into a curve on a two-lane rural road, with opposing traffic. Due to a green tractor traveling at 20 mph, initially 300 m ahead of the first car (VA ~ 0.72°), the vehicles started to brake consecutively (1st car when within 70 m from the tractor and at a deceleration of 1 m/s^2, 2nd car when within 21 m of the 1st car at 2 m/s^2, 3rd car when within 24 m of the 2nd car at 2.5 m/s^2, 4th car when within 21 m of the 3rd car at 2.5 m/s^2, and the last car when within 37 m of the 4th car at 2.5 m/s^2). This chain braking required 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 mph to 20 mph, so that aside from their brake lights, the visible deceleration and diminishing headway distances between them were further cues. The event in this scenario was defined as the braking of the vehicle directly ahead of the participant. If the participant had not acted on any of the cues until this point, he had to act at this point to avoid collision.

For this scenario, the most important cue was the slow tractor, which was ahead of the chain of five vehicles and therefore not necessarily the focus of attention. Both interfaces therefore concentrated on highlighting the slow tractor, again with the attentional interface limited to just warning the driver of the tractor, while the interpretational interface also displaying the potential consequence, with a depiction of the following two cars braking as a representation of the chain deceleration that was about to occur (Fig. 2c). The interfaces were displayed at the same point in time prior to the lead car braking.

Before the simulator experiment, these six anticipatory interfaces (Fig. 2) were subjected to a small-scale usability testing to ensure that they were easily understandable and would not generate dangerously-long off-road glances. First, 24 evaluators interpreted the interfaces in a multiple choice survey, which showed that everyone had understood the information content. Then, another five evaluators viewed the two interfaces for two seconds each and were asked to interpret them. This viewing duration was chosen due to research showing off-road glances greater than 2 s to significantly increase crash risks (Dingus et al., 2006). No evaluator failed to understand the meaning of any display within the two-second exposure time.

2.5. Procedure

Participants were first told that the general purpose was to study driving behavior 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 behavior 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 the above default behaviors. The first run gave them an opportunity to drive on a rural road below 40 mph and follow a lead vehicle, while the second run involved a merge onto a highway as well as practice at maintaining a highway speed of approximately 60 mph. The practice sessions took approximately 10 min in total and ended when the participants and the investigator were both content with the performance achieved. Following the practice sessions, the investigator calibrated the eye-tracker. The participants then completed the nine drives, each one lasting three to five minutes. After all drives were completed, participants were given a digital post-experiment questionnaire. As part of this post-experiment questionnaire, they filled out mental effort (Zijlstra, 1993) and driver technology-acceptance scales (Van der Laan et al., 1997). Total time for the experiment varied between 1.5 and 2 h per participant, and compensation was set at C$20.

3. Results

In this section, we report on whether drivers exhibited pre-event responses, their perceived mental effort for the three scenarios, their glances to the in-vehicle display, and their acceptance of the two interfaces. We do not report on traditional driving performance measures (e.g., reaction times or time to collision) as our focus is on promoting and identifying anticipation, a high-level competence. Although anticipation has the potential to improve driving performance when used for one specific goal, i.e., safety, it may also serve other goals, such as eco-driving, which may at times conflict with maximizing safety margins. The consequences of anticipation therefore depend on the individual goals of the driver, and we decided not to impose too much experimental control within the scenarios in favor of observing natural behavior. In fact, our previous study (Stahl et al., 2014b), where we adopted the same approach of observing natural behavior, revealed that heightened anticipation did not consistently result in improved safety as assessed through time to collision and headway time.

3.1. Pre- and post-event responses

Drivers were categorized into pre- and post-event response groups based on whether or not they acted prior to the defined event in each scenario using the same methods employed in Stahl et al. (2014b). 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, which was also considered an appropriate pre-event action. Drivers were categorized into pre- and post-event response groups by the first author, who was blind to the corresponding experimental conditions, including driving experience, interface type, and experimental phase.

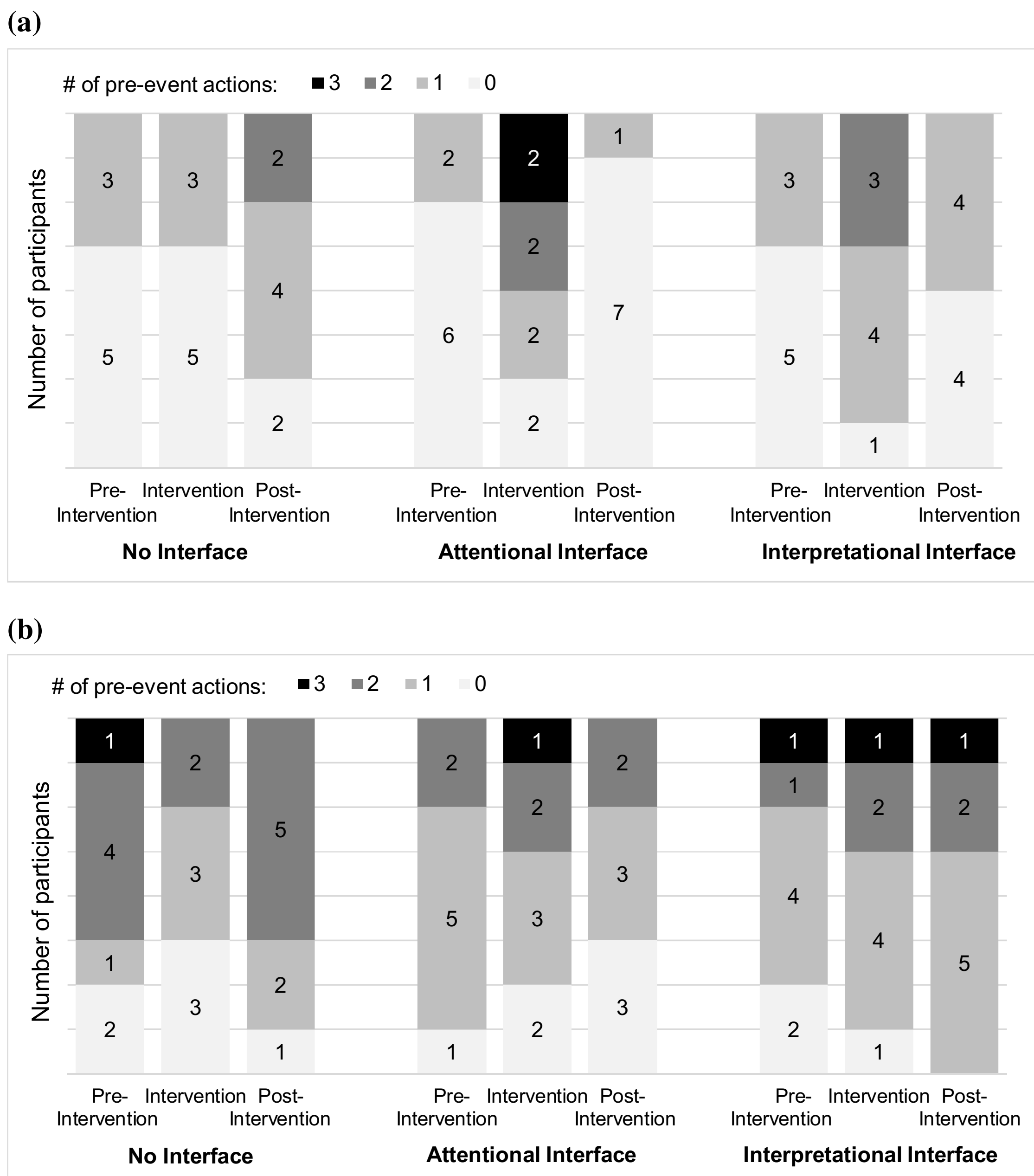

Fig. 3. Number of pre-event actions taken by novice drivers (a) and experienced drivers (b) across three blocks of drives (pre-intervention, intervention, and post-intervention) in each of the three interface conditions (no interface, attentional interface, and interpretational interface).

From a descriptive standpoint, Fig. 3a shows that novice drivers assigned to the 'no interface' condition appeared to have a relatively stable number of pre-event responses across the different experimental phases. In contrast, the novice drivers assigned to the attentional or interpretational interface conditions appeared to exhibit a higher numbers of pre-event actions during the intervention phases. Again from a descriptive standpoint, the number of pre-event actions taken by experienced drivers appeared to be much higher in general (Fig. 3b), with some participants exhibiting all three pre-event actions before the interfaces were presented. However, there were no major improvements apparent with the interfaces.

A cumulative logit model was built to analyze number of pre-event responses per experimental phase exhibited by each driver. Given that there were three scenarios per phase, this dependent variable could take on values of 0, 1, 2, or 3. Because the number of participants who acted pre-event in all three scenarios was small, we collapsed the dependent variable into three categories: 0, 1, and $\geq$2 pre-event actions. Through this model, we compared the pre-event responses of novice and experienced drivers across the pre-intervention phase (i.e., baseline) and then investigated the effectiveness of the anticipatory interfaces for each experience group. The latter was achieved through specific contrasts which, for a given anticipatory interface (i.e., attentional or interpretational), first obtained the change from the pre-intervention phase to the intervention phase and then compared it to that obtained for the 'no interface' condition (i.e., control group). We fit the model using the GENMOD procedure in SAS 9.3, with the specifications of cumulative logit link function and multinomial distribution. Generalized estimating equations were utilized for repeated measures. The specific contrasts were set through the 'Estimate' statement.

3.1.1. Novice driver performance

For both interface conditions, the likelihood of novice drivers exhibiting pre-event actions increased from the pre-intervention to the intervention phase. With the interfaces, the odds of exhibiting pre-event actions increased more than tenfold (attentional interface: Odds Ratio (OR) = 19.8, $\chi^2(1) = 6.10$, $p = 0.01$; interpretational interface: OR = 10.2, $\chi^2(1) = 6.91$, $p = 0.009$). In contrast, novice drivers who were in the 'no interface' condition did not show any significant changes from the pre-intervention to the intervention phase (OR = 1, $\chi^2(1) = 0$, $p = 1$), suggesting that there were no major learning effects from the first phase to the second when there was no anticipatory interface present. As an additional check, we compared the change from the pre-intervention to the intervention phase obtained for the interface conditions (i.e., attentional and interpretational) to that obtained for the 'no interface' condition. Both comparisons led to marginally significant results (attentional interface: OR = 19.8, $\chi^2(1) = 3.56$, $p = 0.06$; interpretational interface: OR = 10.2, $\chi^2(1) = 2.96$, $p = 0.09$). The improvements with the two interfaces appeared to bring novice drivers' performance on par with the experienced group. In particular, there were no significant differences observed when pre-event actions were compared across the two experience groups when they were presented with the interfaces (attentional interface: OR = 0.7, $\chi^2(1) = 0.15$, $p = 0.7$; interpretational interface: OR = 1, $\chi^2(1) = 0$, $p = 1$).

Going from the intervention phase to the post-intervention phase, the 'no interface' group showed an increased likelihood in exhibiting pre-event actions, suggesting a learning effect (OR = 5.4, $\chi^2(1) = 10.89$, $p = 0.001$), while both the attentional (OR = 0.02, $\chi^2(1) = 5.37$, $p = 0.02$) and the interpretational interface groups (OR = 0.15, $\chi^2(1) = 4.59$, $p = 0.03$) showed a decline in pre-event response likelihood in the post-intervention phase. When the change from pre-intervention to post-intervention phases was compared across different interface types, the attentional interface was found to perform marginally worse compared to the 'no interface' condition (OR = 0.08, $\chi^2(1) = 3.29$, $p = 0.07$).

3.1.2. Experienced driver performance

A comparison of novice and experienced drivers during the pre-intervention phase revealed that, as expected, experienced drivers exhibited more pre-event actions (OR = 10.8, $\chi^2(1) = 16.40$, $p < 0.0001$). Going from the pre-intervention to the intervention phase, the anticipatory interfaces were not found to make a difference for the experienced drivers (attentional interface: OR = 1.06, $\chi^2(1) = 0$, $p = 0.1$; interpretational interface: OR = 1.9, $\chi^2(1) = 0.61$, $p = 0.4$). A marginally significant difference was found for the 'no interface' condition, with a decline in pre-event response likelihood from the pre-intervention to the intervention phase (OR = 0.2, $\chi^2(1) = 3.39$, $p = 0.07$). Overall, the change from the pre-intervention to the intervention phase for the attentional interface was not significantly different than that of the 'no interface' condition (OR = 5.3, $\chi^2(1) = 1.7$, $p = 0.2$). However, the change from the pre-intervention to the intervention phase for the interpretational interface was marginally better than that of the 'no interface' condition (OR = 9.5, $\chi^2(1) = 3.42$, $p = 0.06$).

Going from the intervention phase to the post-intervention phase, the 'no interface' group showed a marginally significant increase in likelihood of exhibiting pre-event actions (OR = 11, $\chi^2(1) = 3.31$, $p = 0.07$). In contrast, performance changes in both interface groups were not significant (attentional interface: OR = 3.1, $\chi^2(1) = 1.96$, $p = 0.2$; interpretational interface: OR = 0.8, $\chi^2(1) = .09$, $p = 0.8$). When the change from pre-intervention to post-intervention phases was compared across the three interface types, again no significant differences were observed.

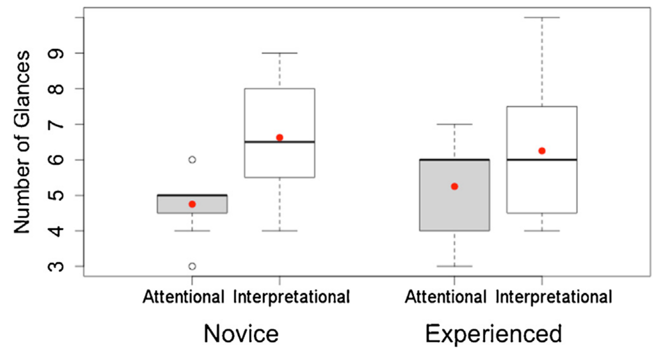

Fig. 4. Number of glances toward the display across interface type and experience level (in this and all following boxplots we present minimum, first quartile, median, third quartile, and maximum, as well as potential outliers indicated with hollow circles and means indicated with solid circles).

3.1.3. Perceived mental effort

At the end of the experiment, participants rated their perceived mental effort for each of the three scenarios on a 0–150 scale (Zijlstra, 1993). We averaged the three values into one global mental effort rating per participant and built a linear model with the MIXED procedure in SAS 9.3, using interface type, experience, and their interaction as predictors. In accordance with the superior performance of experienced drivers with respect to number of pre-event actions, experienced drivers rated their mental effort within our scenarios significantly lower than novice drivers, with average ratings of 33.9 and 45.8, respectively ($F(1,42) = 4.48$, $p = 0.04$).

3.2. Display glances

Overall, 32 participants completed three scenarios with the attentional or the interpretational interface conditions during the intervention phase. The following glance measures were analyzed to assess how these participants interacted with the interfaces over these three scenarios: (1) total number of glances toward the in-vehicle display, (2) maximum display glance duration, and (3) mean display glance duration. These variables were analyzed through mixed linear models built in SAS 9.3 MIXED procedure, with interface type, experience, and their interaction as predictors.

There was no interface type—experience interaction for number of glances ($F(1,28) = 0.61$, $p = 0.44$), mean glance duration ($F(1,28) = 1.27$, $p = 0.27$), or for maximum glance duration ($F(1,28) = 1.51$, $p = 0.23$). Overall, the participants glanced at the interpretational display more frequently (Fig. 4), with an average total glance number of 5 with the attentional interface and 6.44 with the interpretational interface ($F(1,28) = 6.58$, $p = 0.02$). A marginally significant finding was observed for mean glance duration ($F(1,28) = 3.30$, $p = 0.08$), with the interpretational interface having a 0.15 s longer mean glance duration, but no difference was observed between the two interface types for maximum glance duration ($F(1,28) = 2.60$, $p = 0.12$) (Fig. 5).

On the average, novice drivers had longer mean (difference: 0.18 s, $F(1,28) = 5.29$, $p = 0.03$) and maximum glance durations (difference: 0.32 s, $F(1,28) = 4.39$, $p = 0.045$) toward the display, but there was no effect of experience on number of glances ($F(1,28) = 0.01$, $p = 0.91$). There was one experienced driver who had one glance longer than 1.6 s (a margin used in previous research, e.g., Bischoff (2007) and Wierwille (1993)), whereas six glances longer than 1.6 s were recorded for novice drivers (4 drivers total), one of which was longer than 2 s. The breakdown of these long glances across the two interfaces was fairly even.

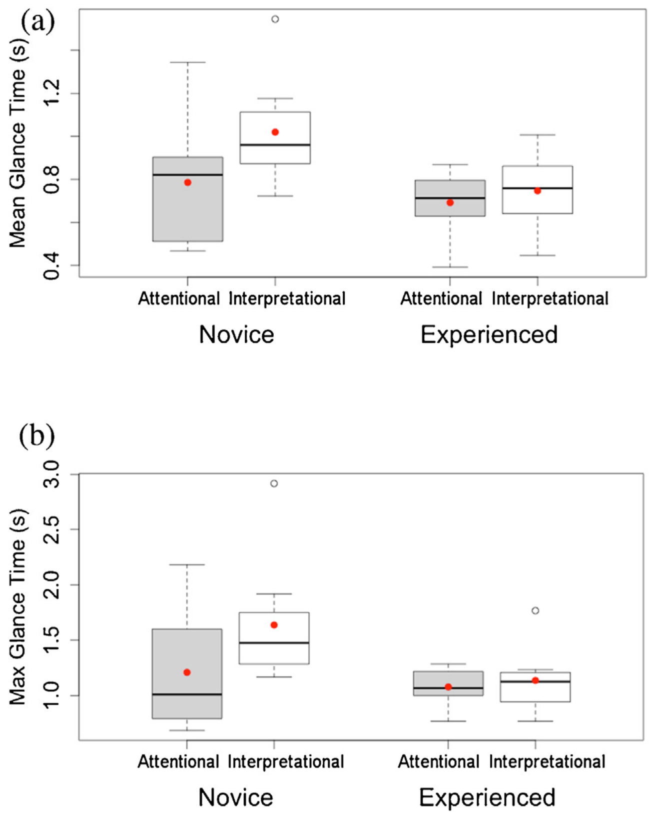

Fig. 5. Mean (a) and maximum (b) glance duration toward the display across interface type and experience level.

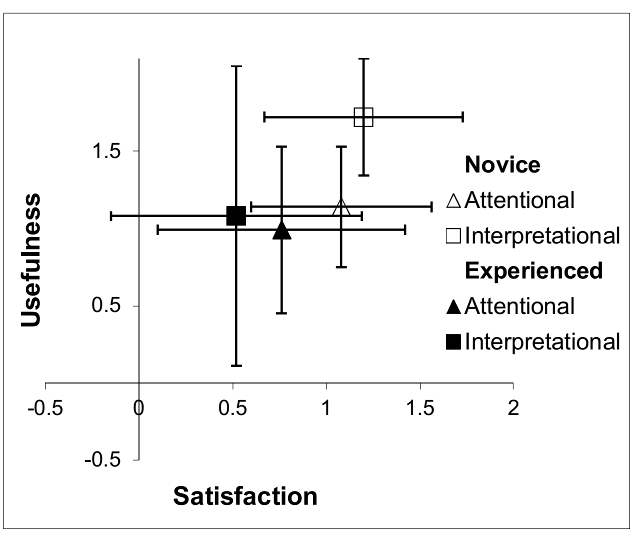

Fig. 6. Mean interface acceptance ratings obtained from raw data; error bars represent one standard deviation.

3.3. Interface acceptance ratings

The 32 participants who were in the attentional or the interpretational interface conditions were asked to fill out the system acceptance questionnaire designed by Van der Laan et al. (1997) for the respective interface they had experienced. This questionnaire has 9 items collected on a scale of −2 to 2, investigating two constructs: usefulness and satisfaction (Fig. 6). Separate linear models were built with the MIXED procedure in SAS 9.3, one for usefulness and one for satisfaction, with interface type, experience, and their interaction as predictors. Experience had a significant influence on satisfaction ratings ($F(1,28) = 5.75$, $p = 0.02$), with novice drivers giving average ratings of 1.14 and experienced drivers giving 0.64. Experience had a marginally significant effect on ratings of usefulness ($F(1,28) = 3.29$, $p = 0.08$), with novice drivers giving average ratings of 1.43 and experienced drivers giving 1.03.

4. Discussion

A driving simulator study investigated the effectiveness of two interface types proposed to support anticipation in driving. The attentional interface focused on calibrating attention to relevant cues, whereas the interpretational interface provided likely consequences based on these cues in addition to guiding drivers' attention to the cues. These two interfaces were evaluated with novice and experienced drivers. Without the interfaces, experienced drivers demonstrated superior anticipatory competence by taking more pre-event actions than novice drivers, a finding in line with our earlier work (Stahl et al., 2014b). The interfaces enhanced the anticipatory actions taken by novice drivers, whereas no significant effects were observed for experienced drivers. The benefits of the interfaces diminished once they were removed.

Contrary to our expectation, the experienced drivers did not show significant improvements in performance with either display. We hypothesized that directing the attention of this group of drivers to relevant cues would increase the number of pre-event actions taken. The lack of significant findings here might be due to sample size limitations, or to the fact that experienced drivers were already attending to relevant cues. Notably, however, there were no distractions present in the experimental scenario. In general, driver distraction is a growing concern with the continual introduction of technologies to the vehicle (Regan et al., 2009). Anticipatory interfaces may prove beneficial in mitigating distractions and future research should investigate the effectiveness of these displays under multitasking scenarios.

As expected, novice drivers exhibited an increased number of pre-event actions with the two anticipatory interfaces. In fact, the improvement was high enough for the novice drivers' performance to match that of experienced drivers. In line with this objectively assessed benefit, novice drivers gave significantly higher acceptance (usefulness and satisfaction) ratings to both interfaces than experienced drivers who were generally accepting of the interfaces. Facilitating anticipation through in-vehicle displays therefore appears to be a promising strategy to counteract the known risks associated with lack of experience, particularly the identification of risks (Jackson et al., 2009) and the related problem of targeted visual search (Fisher et al., 2007). While the positive influence of driver experience on anticipation skills has never been in question, a tangible understanding for what constitutes experience is elusive. This research shows that anticipation is a concrete aspect of experience that contributes to the heightened skill of experienced drivers.

We did hypothesize the interpretational interface to generate additional benefits for the novice drivers with the assumption that novice drivers would not only lack the competency to focus on important cues, but also have more difficulty interpreting the situation correctly due to a smaller catalog of stereotypical situations. Focusing attention on the relevant cue for an upcoming conflict alone proved sufficient to improve performance, but the reason for this finding is unclear and requires further research. The lack of difference between the two interface types may suggest that novice drivers suffer more from improper attention allocation and less from correct interpretation of the traffic situation. It is also possible that alerting participants to a particular cue in itself may trigger a defensive action by proxy. That is, participants may not necessarily have understood the meaning of the attentional interface, but may have just released the accelerator to be cautious (releasing the accelerator was a favorable action in our scenarios, but may actually exacerbate conflicts in other situations). This hypothesis can be tested in the future by comparing the anticipatory interfaces to a warning-only condition (e.g., Baldwin and May, 2011; Werneke and Vollrath, 2013), which does not refer to the relevant anticipatory cues. It can also be tested by employing scenarios in which deceleration would be disadvantageous. Other potential explanations include sample size limitations as well as how the interfaces were operationalized. In particular, the information included in the attentional interfaces may have, to some extent, facilitated additional situational understanding. In order to further investigate the effect of interface information content on driver's interpretation of the traffic situation, query- or probe-based measures (Salvendy, 2012) can be used in future research.

Although the interfaces proved to be beneficial for novice drivers, the benefits appeared to disappear once the interfaces were removed in the post-intervention phase. Further exposure to the interfaces may create more lasting effects by facilitating learning and should be investigated in future research. The interpretational interface may in particular help the novice drivers form a catalog of stereotypical situations, which may not be facilitated as well by the attentional interface or an interface that would suggest an action without aiding interpretation (e.g., "slow down and merge"). This latter interface type was not investigated in the current paper but is a point of future research.

Another positive finding about these interfaces was the very few number of long off-road glances observed. Glances longer than 2 s have been shown to increase crash risks (Dingus et al., 2006). In our simulator study, only one glance that was longer than 2 s was recorded. Overall, independent of experience level, the attentional interface resulted in fewer and shorter glances than the interpretational interface, likely due to the reduced amount of information presented on the attentional interface. Driver experience also affected glances directed toward the interfaces. Novice drivers had higher mean and maximum glance durations than the experienced drivers. Thus, while novice drivers profited far more from the interface intervention, they also took their eyes off the road more frequently and for longer durations. Given these findings and the lack of pre-event action differences between the two interfaces for the novice drivers, the attentional interface appears to be the better alternative for this group of drivers.

On a more general level, the results of this research support the approach of facilitating anticipation through the use of real-time in-vehicle displays. From a practical standpoint, with vehicle-to-vehicle and vehicle-to-infrastructure communications (Papadimitratos et al., 2009), it would be feasible to implement anticipatory displays in the car such as the ones tested in this study. Up to this point, however, we have made efforts to study anticipation through drivers' natural behavior, independent of their specific goals. Future research should investigate the potential of more goal-oriented support of anticipation such as for maximizing safety or eco-driving. Such research can more directly lead to practical applications in the form of implementable interfaces.

Aside from having investigated only observable results of the interface interventions, as opposed to the changes in mental models of the traffic situations, further limitations apply with respect to the scenarios investigated. For future research, anticipation should be investigated in a larger variety of traffic situations, particularly also such in which deceleration would not be a favorable action. Further, known limitations apply due to the use of a simulator, such as the potential inflation of effects of driver skill, or the validity of performance measures (Mullen et al., 2011).

5. Conclusion

Prior research established that experienced drivers are frequently able to anticipate future traffic situations and take action to avoid potential conflicts. This paper extends on this work by theorizing about the perceptive and cognitive mechanisms that may allow for that anticipation. We hypothesized two crucial mechanisms for the successful anticipation of future traffic states—the calibration of a driver's senses such that important cues are recognized, as well as the correct interpretation of the meaning of these cues. According to these mechanisms, two interface types were designed and their effects were investigated in a simulator experiment. Results showed that both interfaces had a positive impact on the number of pre-event actions novice drivers took, but showed no difference in performance between the two interface types. Given the longer and more frequent glances to the interpretational interface, the attentional interface appears to be the better choice for novice drivers.

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