Summer 8-2023

Operational Hazard Anticipation: Examination of Overt Anticipatory Behaviors in Latent Hazard Scenarios Using a High-Fidelity Driving Simulator

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OPERATIONAL HAZARD ANTICIPATION: EXAMINATION OF OVERT ANTICIPATORY BEHAVIORS IN LATENT HAZARD SCENARIOS USING A HIGH-FIDELITY DRIVING SIMULATOR

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A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

PSYCHOLOGY

OLD DOMINION UNIVERSITY
August 2023

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ABSTRACT

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Young drivers are more likely to be involved in fatal crashes compared to more experienced drivers. Perceptual-cognitive skills such as anticipating and mitigating hazards may contribute to this risk. However, the connection between anticipating a hazard and successfully mitigating said hazard is not clear. One novel concept that may bridge hazard anticipation and mitigation is operational hazard anticipation. *Operational hazard anticipation* is the act of engaging in anticipatory actions in preparation for the possibility of eventual hazard mitigation. This study examined a possible measure of operational hazard anticipation, hovering one’s foot over the brake and accelerator, and the relationship between latent tactical hazard anticipation and operational hazard anticipation. Exploratory analyses were conducted to examine the possible relationship between operational hazard anticipation and collision avoidance performance. Inexperienced and experienced drivers drove through eight simulator scenarios, each with either a behavioral hazard (the hazard and precursor are the same) or an environmental hazard (the hazard and precursor are different objects). Experienced drivers engaged in operational hazard anticipation behaviors more frequently than inexperienced drivers and these behaviors were seen more frequently in behavioral scenarios compared to environmental scenarios. In addition, participants’ average operational hazard anticipation score was positively related to successfully avoiding a collision when the hazard was environmental. These findings

support operational hazard anticipation as a skill set distinct from tactical hazard anticipation and can offer insights into how to train young inexperienced drivers to successfully avoid hazards on the road.

This work is dedicated to my family and friends
who nurtured and encouraged me
over the past five years.

ACKNOWLEDGEMENTS

Research cannot be accomplished in isolation, and this dissertation was no exception. I would like to thank the members of my committee, Dr. Xiao Yang and Dr. Sherif Ishak for the time and effort that they gave to make this work the best it could be. Your suggestions and ideas offered me different perspectives and made this research much stronger.

In addition, I have so much gratitude for the members of our Applied Cognitive Laboratory. From offering feedback on presentation to being open to discussing the latest research ideas, I appreciate everything Tetsuya Sato, James Unverricht, Shelby Long, Mike Politowicz, Jeffrey Glassman, and Jessica Inman helped me with to make this document possible. A huge thank you to Peggy Kinard and Linda Forchas for help navigating the program and supporting me (and the whole Psychology department) at every step.

Finally, I would like to thank my adviser, Dr. Yusuke Yamani. The amount of care, thought, and time that you have put into your students and their work is beyond compare. Over the past five years, I am become a more confident and independent researcher because of your mentorship. Thank you so much for your guidance, support, and encouragement.

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CHAPTER I

INTRODUCTION

Despite a general decline in the number of fatal automobile crashes involving young drivers aged 15-20 over the past decade (NHTSA, 2019), young drivers are almost three times more likely to be in a fatal crash compared to drivers over the age of 20 (IIHS, 2021). McKnight and McKnight (2003) showed that failures of attention and insufficient search of the environment were contributing factors to 23% and 42.7% respectively of 2,128 police-reported non-fatal crashes involving young drivers, while only 0.7% of crashes were attributable to high speed. This result indicates that young novice drivers are not careless but are instead clueless in respect to where in the road environment they should be searching and maintaining attention, opening the possibility to train these perceptual-cognitive skills that allow them to effectively scan an immediate road environment and mitigate imminent road hazards.

Two higher order cognitive skills that younger drivers are found especially poorer at are *hazard anticipation* and *hazard mitigation*. Hazard anticipation (HA) is the ability to anticipate the presence of a hazard before it materializes on the road (Unverricht et al., 2018). Hazard mitigation (HM) is the ability to reduce the chance of a collision based on their evaluation of a hazard (Pradhan & Crundall, 2017). This dissertation examines the novel concept of *operational hazard anticipation* as a set of possible skills that bridges HA and HM performance. Briefly, operational HA refers to cognitive skills that prepare a driver for a HM action. Engaging in anticipatory actions such as hovering one’s foot over the brake pedal after anticipating a hazard may help drivers successfully mitigate said hazards. Using a high-fidelity driving simulator, inexperienced and experienced drivers navigated driving environments that contain both *behavioral* and *environmental* hazards. Behavioral hazards are classified as when the hazard and the precursor (clue regarding the presence of the hazard) are the same object, whereas environmental hazards consist of different hazards and precursors. Young, inexperienced drivers have been found to be worse at anticipating environmental hazards (where the precursor and the hazard are different objects) compared to experienced drivers yet fixate on the environmental precursors at the same rate as experienced drivers (Crundall et al., 2012). Further, the same study showed inexperienced drivers were less likely to fixate on behavioral hazard precursors than experienced drivers. I hypothesized that young, inexperienced drivers would engage in operational HA (motor preparation for a mitigation action) less frequently compared to experienced drivers. The results will contribute to deepening the theoretical understanding of how drivers perceive and anticipate hazards and prepare motor responses for an event that they must execute to mitigate said hazards.

CHAPTER II

TAXONOMY

In the context of driving, a *hazard* is a dangerous or potentially dangerous traffic situation, object, or event that could cause injury or property damage for the driver or other road users (Barragan et al., 2021). An *overt hazard* is a hazard that is present on the road and visible to a driver (Pradhan & Crundall, 2017). A *latent hazard* is a hazard not directly visible to the driver and has not materialized on the road yet (Unverricht et al., 2018). However, a driver may use hazard precursors to help them guess the presence of upcoming hazards and where hazards are located. A *precursor* is a clue to an upcoming hazard (Pradhan & Crundall, 2017; Krishnan et al., 2019). Precursors can be an *environmental* element (e.g., "Crosswalk ahead" sign or a van obscuring the entrance of a crosswalk) or it can be a *behavioral* precursor which is the same stimulus as the hazard but before it materializes as a hazard (e.g., a pedestrian walking on the sidewalk who might later enter the roadway) (Crundall et al., 2012).

Hazard avoidance is the overarching process of avoiding a collision with a hazard (Pradhan & Crundall, 2017). Hazard avoidance encompasses several steps, from a driver's initial search for hazards in the environment to their successful selection and execution of a suitable response to avoid hazards that appeared on the road. Two subprocesses of hazard avoidance discussed below are HA and HM. HA involves the search, detection, comprehension, and prediction of latent hazards (Unverricht et al., 2018). For example, when the view to the entrance of a midblock crosswalk located on the road ahead is blocked, a driver should anticipate that a pedestrian about to step into the road may be *hidden* behind van. Even if a hazard does not materialize, the driver should anticipate that a pedestrian might be behind the van by glancing to the target area. On the other hand, HM refers to overt driving behavior that reduces the probability of a crash with a future hazard that is successfully anticipated (Muttart & Fisher, 2017). For example, a driver should slow down when turning to the left at a stop-controlled four-way intersection when the driver sees a pedestrian approaching to the entrance of a crosswalk but does not actually cross the road.

This dissertation compared latent HA in scenarios with environmental and behavioral hazards between young and experienced drivers. Furthermore, I examined behavioral manifestations of operational HA between the groups as a process that bridges HA and HM.

CHAPTER III

COGNITIVE SKILLS CRITICAL FOR ROAD SAFETY IN YOUNG DRIVERS

Hazard Anticipation

The development and analysis of specific HA scenarios has been critical to the study of HA performance, development, and training interventions. Pradhan and colleagues (2005) created 16 risky scenarios with a variety of hazards and examined HA performance of young and older drivers on the scenarios modelled in a driving simulator. These scenarios contained overt hazards, latent hazards, and emerging hazards. On average, novice drivers (16-17 years old) fixated on the risky element in only 36% of the trials, compared to 51% of the time with younger drivers (19-29 years old) and 66% of the time with older drivers (60-75 years old). In some scenarios, the differences between novice, younger, and experienced drivers were stark. For example, the scenario where a truck is blocking the view of the entrance to a crosswalk (one of the most commonly referenced latent hazard scenarios) resulted in novices only fixating on the hazard 9.5% of the time, younger drivers 28.6% of the time, and experienced drivers 57.1% of the time. This study demonstrated not only that novice (16-17 years) drivers were alarmingly poorer at HA compared to other age groups, but also that HA skills are still underdeveloped with drivers in the 19–29-year range, suggesting that even drivers in their twenties may benefit from HA skill training. The finding that fatal crash risk sees a marked decrease after 30 years of age highlights the possible relationships between driving experience, HA skills, and crash risk (Tefft, 2017).

Researchers have suggested various ways to measure HA. Crundall (2016) showed real-life traffic situation clips to both experienced and inexperienced drivers who were simply tasked at predicting “what happened next” after the clip ended. In this experiment, participants viewed 30 hazardous (along with 10 non-hazardous) video clips which cut to black just prior to a hazard occurring, with precursors to the hazard also present in each clip. The results indicated that experienced drivers were more accurate than inexperienced drivers at predicting what hazard would have occurred had the clip continued. This technique developed and used by Crundall (2016) reflected a view of HA being equivalent to the projection stage (Level 3) of situation awareness (SA) framework (Endsley, 1995). Briefly, Endsley (1995) contended that Level 3 SA consists of the ability to project the future actions of elements in our environment after first perceiving (Level 1) and comprehending (Level 2) the element. The application of the HA process to the SA model is discussed in more detail below. Other researchers measure HA by showing participants video clips of real-life traffic scenarios and asking them to press a button every time they see a hazard or a potential hazard (Borowsky et al., 2009; Meir et al., 2014). With this paradigm, both the binary response to the hazard and the response time (RT) to the hazard can be used as a measure of HA.

Unlike other HA measures, latent HA is measured using drivers’ eye movements when driving through scenarios with latent hazards defined *a priori*, either in a simulator or on the road (Pradhan et al., 2005). A successful latent HA occurs when the driver glances at the area that contains the latent hazard (the *target zone*) while driving through the area before the latent hazard (the *launch zone*) (Unverricht et al., 2018; Yahoodik & Yamani 2021; Yamani et al., 2016, 2018). Latent HA performance scoring is binary with the driver either successfully anticipating the hazard (score of 1) or failing to anticipate the hazard (score of 0).

Eye tracking can also be used to examine the relationship between anticipating hazards and the driver's encoding of precursors that provide information on the presence of upcoming hazards. Inexperienced drivers struggle to anticipate latent hazards, perhaps due to the indirect relationship between the hazards and the precursors (Crundall et al., 2012). Using the truck-obstructed crosswalk scenario for example, the hazard (should it appear) is a pedestrian, but the precursor that signals to the driver the presence of the hazard is the truck itself. Alternatively, if a driver sees a pedestrian walking along the sidewalk, the pedestrian acts as both the hazard (they could potentially step into the street) and the precursor (the presence of the pedestrian signals the possibility that they may suddenly step into the street). In a driving simulator study, Crundall and colleagues (2012) examined group differences between learner drivers, experienced drivers, and driving instructors by studying fixations towards behavioral hazards and precursors (hazard and precursor are the same object) and environmental hazards and precursor (hazard and precursor are different). Unlike previous latent HA studies, a hazard materialized for each scenario. Surprisingly, learners fixated on the less salient environmental precursors at a similar rate as experienced drivers and instructors but missed more environmental hazards than the experienced drivers and instructors. This could suggest that, even if inexperienced drivers fixate on these environmental precursors, without knowledge and experience, they might not encode that the precursor predicts a potential hazard. However, preliminary research has demonstrated that such skill deficits may be amenable to training (Krishnan et al., 2019). Using a novel driver training program, young drivers trained on both latent hazards and how to use precursors to predict latent hazard showed better latent HA performance and more fixations on the hazard precursors in a driving simulator evaluation drive compared to participants who underwent a placebo training.

Although research is conflicted on whether young novice drivers engage in distracted driving (such as cell phone use) more frequently than older drivers (Durbin et al., 2014), a recent study suggests that engaging in a secondary task has a negative impact on HA (He & Donmez, 2022). In a simulator study, inexperienced and experienced drivers drove through scenarios in which a hazardous event occurred (such as a car trying to merge or a lead vehicle braking in response to a slow truck ahead) with each event being cued in advanced by a precursor. Half of the participants also engaged in a self-paced, secondary visual-manual task. Experienced drivers fixated on the precursor more than inexperienced drivers, but the proportion of both experienced and inexperienced drivers who fixated on the cue was smaller in the secondary task group. This finding suggests that experienced drivers are not immune to the effect of distraction on HA performance, but considering inexperienced drivers exhibit lower baseline HA performance, they may be especially at risk to the effects of distracted driving.

Researchers have more recently delineated four different levels of latent HA based on the nature of the precursor and the relative location of the vehicle in terms of the hazard (Yamani et al., 2021). The most general, modal HA, involves responding in a systematic way to general traffic, environmental, and road geometry conditions. *Modal* HA is most clearly demonstrated in the difference in distribution of eye movements on the road between novice and expert drivers. For example, experienced drivers displayed a wider distribution of glances compared to novice drivers (Mourant & Rockwell, 1972). *Strategic* HA involves using hazard precursors to predict hazards (such as a sign that indicates a crosswalk is ahead). *Tactical* HA involves looking for the presence of a potential hazard in their immediate road environment (such as looking for a pedestrian that may step out into an approaching crosswalk when the entrance is visually obscured). Finally, *operational* HA is the act of engaging in anticipatory actions in preparation for the possibility of eventual HM. For example, if a driver is approaching the above crosswalk, they may hover their foot over the brake pedal in preparation for the possibility of a pedestrian stepping out into the street from behind the van. Operational HA is distinct from HM (described below) in that the driver has not yet executed an action to avoid or reduce the risk of collision with a hazard. That is, operational HA is the driver's *readiness* to execute a mitigating response.

Training

Several training programs have been developed to accelerate the acquisition of HA skills in novice drivers. The format and modality of these trainings vary. For example, the Act and Anticipate Hazard Perception Training (AAHPT) uses video clips of real-life driving scenes to expose novice drivers to a wide variety of traffic situations and hazards in a relatively short amount of time (Meir et al., 2014). Participants are tasked with pressing a button every time they see a hazard or potential hazard on the screen. Between the three versions of AAHPT tested, the most effective one combined the traffic clips with a module that explained the nature of latent hazards and where they might be located. This concept of using video clips to test drivers' ability at recognizing overt hazards and anticipating latent hazards is not new; these types of hazard perception tests have been part of the official licensing process in in the UK and Australia since 2002 (Horswill & McKenna, 2004).

Despite the diversity of HA training, no training has been as extensively evaluated as the Risk Awareness and Perception Training (RAPT) program (Pradhan et al., 2009; Unverricht et al., 2018; Yamani et al., 2018; Yahoodik & Yamani, 2021). The most recent iteration of RAPT (RAPT-3) involves three modules: a pre-test, training, and post-test (Fisher et al., 2006). In each module, participants are shown nine latent HA scenarios via a series of static photos taken from the driver's perspective as they "navigate" the situation. Participants are tasked with clicking on areas in each picture where they would look for hazards when driving. In the training module, before each scenario, participants are shown a top-down schematic of the traffic environment and are given a description of where latent hazards may be located. If they fail to click on target zones where latent hazards exist, they are prompted to study the top-down schematic again and repeat the trial.

RAPT has been effective at improving latent HA performance in novice drivers both in a driving simulator (Pollatsek et al., 2006) and on the road (Fisher et al., 2007; Pradhan et al., 2009). An on-road evaluation demonstrated that drivers who completed RAPT anticipated latent hazards more frequently for both near-transfer scenarios (the driving environment closely resembled a training scenario) and far-transfer scenarios (the driving environment was conceptually similar to a training scenario, but lacked surface similarities) (Pradhan et al., 2009). The effectiveness of RAPT have been shown to persist for at least six months after training (Taylor et al., 2011). One criticism of HA training is that it is difficult to directly link improved HA performance with a decrease in crash risk (Barragan et al., 2021). However, at least one study has attempted to examine relationship between RAPT and crash risk among young novice drivers. A large scale (*n* = 5,251) naturalistic evaluation study was conducted in California, where newly licensed young drivers (aged 16-18) were randomly assigned to complete either RAPT or a placebo training (Thomas et al., 2016). For the next 12 months, researchers tracked crashes the participants were involved in. Male participants who completed RAPT demonstrated 23.7% reduction in crash rate compared to male participants who completed the placebo training. However, this effect was not found in female participants. Although the gender difference in RAPT effectiveness at reducing crash risk warrants further investigation, RAPT still has the possibility at translating HA performance into safer driver behavior, at least for some groups.

Hazard Mitigation

Compared to the topic of HA, HM has been less studied. This gap in the literature may simply be due to the logistic difficulty of exposing participants repeatedly to HM scenarios in controlled simulator environments. If more than one hazard were to materialize in a single experimental session, participants may become overly sensitized, meaning that they will come to expect hazards around every corner and prepare for them in a way what would be impossible in a real-life driving situation. Despite this, failures in sufficient HM can be linked to the three most common serious crash types for teen-related incidents: left-hand turn crashes, road departures, and rear-end crashes (Braitman et al., 2008). Differences between novice and experienced drivers on HM suggest that HM skills are learned through experience. For example, when evaluated in a driving simulator, novice drivers were less likely than experienced drivers to sufficiently slow down and shift to the outer edge of the lane when entering a curve (Muttart et al., 2013).

HM behaviors are categorized according to two stages: the *potential hazard phase* and the *immediate hazard phase* (Muttart & Fisher, 2017). Actions deployed in the potential hazard phase occur five seconds or more before time to collision with the (potential) hazard. This could include a driver choosing to slow down slightly or changing lanes in case a latent hazard materializes. The immediate hazard phase occurs between 0 and 5 seconds before time to collision and therefore involve more urgent behaviors like hard braking or steering. Ideally, HM should be engaged in the potential hazard phase as opposed to the immediate hazard phase, due to the driver having more time to respond (and engage in addition actions if their original response was not sufficient).

Predictably, HA and HM are closely linked, particularly in the potential hazard phase. It is difficult (if not impossible) to mitigate a hazard if you do not successfully anticipate it being there. This link has been demonstrated in a driving simulator study: both experienced drivers and novice drivers were more likely to slow down when entering a tightening curve if they glanced at the far extent of the curve (area where the curve becomes tight) (Muttart et al., 2013). However, the relationship between anticipating a hazard and mitigating it depends on levels of driving experiences. Whereas 90% of experienced drivers who fixated on the far extent slowed down, only 60% of novice drivers who fixated on the far extent zone slowed down. One possible reason for this finding is that novice drivers did not sufficiently encode the tightening curve as hazardous or had insufficient experience to understand that entering a tightening curve means that one should slow down. Alternatively, novice drivers may not have engaged in appropriate anticipatory actions prior to mitigation (operational HA). We will revisit the topic of operational HA as a potential construct to better connect hazard anticipation and hazard mitigation behaviors below.

In addition to poor HA skills, poor HM skills in inexperienced drivers have been attributed to worse ability to estimate time-to-collision compared with experienced drivers (Muttart et al., 2019), a skill particularly important in safely navigating left-hand turns. Inexperienced drivers are more likely to oversteer or understeer to avoid an obstacle (Muttart et al., 2013) and are less likely to adjust their steering in riskier conditions such as rain and wet roads (Muttart et al., 2015). In addition, inexperienced drivers have been shown to brake with less force than experienced drivers (Loeb et al., 2015). Unfortunately, such technical hazard avoidance skills in the immediate hazard phase are difficult to train in young drivers and may even result in worse safety outcomes. For example, young drivers (aged 18-21) in Finland who completed technical skid training had a greater proportion of crashes in slippery conditions, possibly due to them overestimating their skill level (Katila et al., 2004). Despite the limited success of technical skid training, additional training programs have been developed (and evaluated) to improve young drivers' HM skills.

Training

Because hazard mitigation is a skill gained through experience, training programs that aim to accelerate these skills in new drivers have the potential to offer safety benefits. Anticipation-control-terminate (ACT) training is a PC-based program developed to improve HM skills in novice drivers (Muttart et al., 2019). ACT combines the HA training found in RAPT (where you should look for hazards) with ideal behavioral responses to hazards and high-risk traffic situations. Like with RAPT, participants were shown pictures of nine hazardous driving scenarios novices tend to have the most trouble successfully mitigating (including left-hand turns, curves, and straight road segments at risk of rear-end collisions) three times for the pre-test, training, and post-test modules. Participants were tasked with clicking on areas where they would glance. In addition, they indicated with the mouse when they would brake or slow down and where in the lane they would travel. During the training module, a detailed explanation of the hazards present in each scenario was provided. In addition, participants received feedback on how they should distribute their glances to anticipate hazards and what driving behaviors they should deploy to safely mitigate hazards.

A preliminary evaluation of ACT in a driving simulator shows promise of its effectiveness at improving driver mitigation behavior (Muttart et al., 2019). Novice driver participants first went through the training program before completing an evaluation drive in a driving simulator consisting of driving through two intersections: one where the view of a left-turning vehicle was obstructed and another where they needed to make a left-hand turn with oncoming traffic. Compared with participants who underwent a placebo training, participants trained on ACT crashed less frequently when traveling through the obstructed intersection scenario. In the same intersection scenario, ACT participants were more likely to slow down and slow down earlier than placebo-trained participants. However, there were no significant differences between those in the ACT and placebo group for the left-hand turn scenario. These results suggest that additional evaluations of ACT are necessary to establish the types of driving scenarios where ACT improves hazard mitigation. Because ACT only improved driving mitigation behavior in the obstructed view intersection scenario (a latent hazard scenario where the participant needed to predict a vehicle in the opposite lane could be making a left turn into their path, even though the view of the left turn lane was obstructed), it might be the HA components included in ACT, not the HM components, that improved the safety outcomes in the driving simulator evaluation.

To maximize efficiency in training, a novel training program, SAFE-T, was developed to teach novice drivers three higher-order cognitive skills needed for safe driving: HA, HM, and attention maintenance (the ability to keep attention to the forward roadway) (Yamani et al., 2016). SAFE-T incorporates elements from three trainings: RAPT, ACT and FOCAL (an attention maintenance training). In a driving simulator study, participants who went through SAFE-T demonstrated more HM behaviors (such as accelerating slower after coming to a stop at a crosswalk) compared to participants who completed the placebo group (Yamani et al., 2016). However, participants who went through RAPT showed similar improvements in HM behaviors to those who went through SAFE-T, even though HM is not explicitly taught in RAPT. This finding, coupled with the fact that ACT (a program with hazard anticipation components) only improved HM performance in the latent hazard scenario (Muttart et al., 2019), raises the possibility that RAPT may have benefits beyond simply improving latent HA and could affect HM skills as well.

CHAPTER IV

THEORIES AND FRAMEWORKS OF HAZARD ANTICIPATION AND MITIGATION

There is no single unifying theory to explain how drivers search, detect, evaluate, and respond to hazards and potential hazards on the road (Pradhan & Crundall, 2017) despite the volume of empirical research on HA and HM. As discussed above, some researchers have framed the HA process in the context of situation awareness (SA), with its three levels of processing of surrounding stimuli (Crundall, 2016; Endsley, 1995; Horswill & McKenna, 2004; Strayer & Fisher, 2016). When applied to HA, according to Endley's theory of SA (1995), a driver would first need to detect or *perceive* hazards and potential hazards (Level 1) before *comprehending* the hazard (Level 2). Finally, a driver would then need to *predict* the future status of the hazard (Level 3). SA at these three levels in turn informs the driver's decisions and responses (Endsley, 1995). Although the HA process intuitively fits well with the theoretical framework of SA, the lack of detailed sub-processes and specificity regarding precursors, hazards, and road environments in the model limits its application (Pradhan & Crundall, 2017). In response to the general lack of theory, in the last several years, researchers have developed frameworks to help predict and interpret performance differences in terms of HA and HM.

One such framework is Pradhan and Crundall's (2017) framework which focuses on the different processing requirements needed when driving through four discrete zones of the roadway in relation to the hazard. The *vigilance zone* is the furthest from the hazard and thus, roadway elements in this zone do not pose an immediate threat. However, continuous monitoring of the forward roadway is required in case of changes or developments of the environment, hence the driver needs to maintain *vigilance*. The next closest zone to the hazard is the *strategic zone*, where precursors to the hazard may become evident. When in the strategic zone, the driver may start to engage in HM strategies, but hazards are still too far to warrant an immediate response. In the *tactical zone*, objects and roadway conditions develop into hazards and may require an immediate response from the driver to avoid a collision. The *operational zone* is the closest zone to the vehicle. Because this zone is so close to the vehicle, hazards that suddenly appear in this zone are unlikely to be avoided, assuming they had not been anticipated before entering the zone.

The development of a more recent model of driver-hazard interaction stems from an attempt to link HA and response performance with both basic attention research and driving behavior research (Barragan et al., 2021). The *hazard perception-response framework* (Barragan et al., 2021) is an information-processing stage model where the driver goes through four discrete stages: hazard detection, hazard awareness, response selection, and response. *Hazard detection* involves selectively attending to a hazard or potential hazard and is guided by both bottom-up attributes and top-down schemas of the location of hazards. However, at the hazard detection stage, drivers may fixate on hazard or potentially hazardous objects but fail to encode them as hazardous; this process occurs in the *hazard awareness stage*. Once the driver has been able to detect and evaluate the hazard, they initiate the response selection stage. In the *response selection stage*, the driver determines whether an action is necessary to avoid or mitigate the hazard or potential hazard. If a response is needed, the driver evaluates possible responses and determine which action to execute. In the *response stage*, the driver executes the action (or withholds an action, if action was deemed unnecessary in the response selection stage). The hazard perception-response framework is dynamic in that it assumes that drivers (a) continue to monitor and evaluate potential hazards in the hazard awareness stage if no response was needed and (b) evaluate whether their response was sufficient at avoiding or mitigating the hazard and to engage in additional responses if necessary.

The models proposed by Pradhan and Crundall (2017) and Barragan et al. (2021) can help inform interventions regarding hazard avoidance in addition to hazard avoidance subprocesses. The framework provided by Pradhan and Crundall (2017) contextualizes deployment of hazard avoidance processes by spatial proximity to the hazard, which could inform inexperienced drivers when they should deploy their attention to different road elements and when they should begin to engage in HM behavior. In contrast with Pradhan and Crundall's (2017) framework in which a single hazard (latent or overt) is assumed, the hazard perception-response framework (Barragan et al., 2021) is dynamic and accounts for drivers' continuous monitoring and evaluation of the driving environment for hazards. This type of model could be helpful when examining the process of drivers continually monitoring the roadway and establishing when (and how) a driving scenario previously thought of as benign is classified as a hazard that warrants a response.

CHAPTER V

OPERATIONAL HAZARD ANTICIPATION

Definition

Despite the abundance of research on HA and (to a lesser extent) HM, the exact relationship between the two concepts and, in turn, how to train novice drivers to facilitate hazard avoidance behaviors remain unclear. Even when novice drivers fixate on a hazard, they still exhibit worse HM behaviors compared to experienced drivers who fixated on a hazard (Muttart & Fisher, 2017). As mentioned above, one possible reason for this gap is the difficulty studying hazard mitigation actions in a controlled environment. Yet, isolating ways to improve hazard mitigation performance without unintended negative consequences (Katila et al., 2004) can have serious safety implications, especially for inexperienced drivers (Braitman et al., 2008). One unexplored topic is whether operational HA serves as a link between HA and HM.

Operational HA can be defined as the act of engaging in anticipatory actions in preparation for the possibility of eventual HM and crash avoidance (Yamani et al., 2021). Operational HA is different from other forms of HA in that it requires the driver to decide if an action should be taken, what action should be taken, and when an action should be taken if a hazard were to appear. To put operational HA into the context of the frameworks discussed above, it would likely need to be engaged just before the location of the hazard, in the operational zone as defined by Pradhan and Crundall’s framework (2017). However, if we were to subscribe to a continuous dynamic process of hazard avoidance (Barragan et al., 2021), operational HA may be engaged at various points when driving or approaching a hazard.

Investigating operational HA would be beneficial to theory formation of HM and collision avoidance by determining what subprocesses lead to poor driving safety outcomes and whether driving inexperience affects those subprocesses. Practically, if operational HA indeed affects HM and collision avoidance performance, trainings could be developed to help inexperienced drivers practice such skills in a safe, controlled environment, with the potential of improving driving safety for all on the road.

Theoretical Underpinnings on Response Preparation

Although operational HA has not been explicitly studied and there are not yet validated measures of operational HA or tested interventions, research in experimental psychology offer insights and support operational HA as a concept different from overt motor movements needed for HM. For example, discrete stage frameworks have been used by experimental psychologists to model choice response task performance (Sanders, 1990; Sternberg, 1969; Verwey, 1994). This is not to say that the stages of a choice response model represent the entirety of complex hazard avoidance processes. Indeed, both models of hazard avoidance discussed in the previous chapter (Barragan et al., 2021; Pradhan & Crundall, 2017) emphasize the importance of top-down influences such as expectations, knowledge, and schemas in the detection and mitigation of road hazards, topics which are largely ignored or simplified in choice response models. However, the same stages may apply to select processes of hazard avoidance when driving, which in turn can isolate subprocesses that contribute to operational HA.

Sanders (1990) proposed a stage information-processing model for choice reaction tasks with six stages leading up to the response action: preprocessing, feature extraction, identification, response selection, motor programming, and motor adjustment, with the last three stages being the most relevant to operational HA. Response selection involves matching an appropriate response (R) to the stimuli (S) presented and is therefore influenced by both S-R compatibility and stimulus quality. The motor programming stage is when movement parameters such as speed, direction and force are determined (hence why it is also referred to the "parameter specification" stage). Motor adjustment is the final stage before the execution of the response and can be impacted by elements such as instructed muscle tension and movement specificity.

Practice appears to affect the stages of response selection, motor programming, and motor adjustment differently. In one study, participants completed speeded choice reaction tasks where categorically similar stimuli were mapped onto the same response (Pashler & Baylis, 1991). For example, the digits *2* and *7* were mapped onto the left response key and *P* and *V* were mapped onto the middle response key. When categorically similar stimuli were added to each response (transfer blocks), there was no difference in RTs between the original stimuli and the new stimuli. Additionally, when participants were instructed to use their opposite hand in the transfer blocks, RT did not suffer. However, when the mapping of the response was changed for the categories during the transfer blocks, RTs were slower, suggesting that practice benefits the response selection stage more so than the motor programming or adjustment stages. Beyond simple responses, the formation of complex motor goals and engaging in fine motor movements can initially be costly in terms of RT but can improve with practice (Wong et al., 2015). In addition, advanced knowledge of the required movement sequence reduced RT beyond practice alone. These results could potentially support the concept of operational HA explaining the discrepancy in HM performance between younger and older drivers. First, with more knowledge regarding the possible presence of latent hazards, older adults are better able to prepare possible motor movements should they be warranted. Second, with more experience mitigating hazards, experienced drivers may be able to map hazards more effectively to the appropriate mitigation response.

This dissertation focuses on (a) establishing dependent measures of operational HA and (b) investigating the relationship between operational HA and collision avoidance, HM, and tactical HA behaviors. Possible dependent measures of operational HA that were investigated were hand position on the steering wheel, release of the accelerator pedal, and foot position over the brake pedal (Yamani et al., 2021).

CHAPTER VI

HYPOTHESES

I hypothesized that experienced drivers would engage in operational HA actions more than young drivers, regardless of the type of scenario they were driving through, given that experienced drivers had more practice negotiating risky driving situations and therefore might engage in anticipatory actions in preparations for eventual mitigation. I also hypothesized that for both groups, operational HA performance would be greater during scenarios where the hazard precursor was more salient (behavioral) as opposed to when the precursor was less salient (environmental). With a highly salient precursor, drivers might be more likely to anticipate the precursor eventually becoming a hazard, which in turn might prompt them to engage in operational hazard anticipation. Although a previous study has suggested that novice drivers fixated on environmental precursors at a rate similar to experienced drivers (Crundall et al., 2012), this may have been an artifact of the study design, where a hazard appeared in each scenario. Therefore, I predicted an interaction with tactical HA such that older drivers would have higher levels of tactical HA for both environmental and behavioral hazard scenarios compared to young drivers, but young drivers would fixate on behavioral latent hazards at a rate greater than environmental latent hazards. Considering experienced drivers have had years of practice scanning the driving environment for potential hazards, it is possible that they would engage in tactical HA at the same rate for behavioral and environmental hazards. In contrast, inexperienced drivers might rely on precursor saliency to drive their attention to the hazard. Finally, for the exploratory analysis examining the relationship between operational HA and collision avoidance performance, I predicted that participants who engaged in operational HA actions would be more likely to successfully avoid the hazard when it materializes on the road.

CHAPTER VII

METHODOLOGY

Participants and design

A total of 40 participants participated in this study; twenty young adults (*M* = 18.75 years, *SD* = 0.91, range = [18, 21], 16 women) and twenty middle aged and older adults (*M* = 38.1 years, *SD* = 10.62, range = [30, 64], 9 women). The ages 30-69 was chosen as the "experienced" range because drivers in this age range are at the lowest risk of involvement in a fatal crash (at a rate between 1.04-1.20 crashes per 100 million miles driven) (Tefft, 2017), demonstrating improved driving competency through experience. In contrast, drivers between the ages of 18-19 have fatal crash risk twice as high (2.47 crashes per 100 million miles driven), with even drivers in the range of 20 and 24 years having elevated risk (2.15 crashes per 100 million miles driven). These separate groups were chosen to investigate group differences regarding HA varying as a function of driving experience. All participants had a valid driver's license, and participants in the experienced group had their driver's license for a minimum of three years (Crundall, 2016). In addition, all participants had normal or corrected-to-normal near and far visual acuity and were screened prior to the start of the experiment.

The study employed a 2 × 2 mixed design with driving experience (inexperienced or experienced) as a between-subjects factor and hazard scenario type (behavioral or environmental hazard) as a within-subjects factor.

As a preliminary investigation into the relationship between HA and collision avoidance (CA), at the end of the experiment, participants completed an additional scenario where a hazard materialized. Half of the participants received an environmental CA scenario, while the other half received a behavioral CA scenario.

Apparatus and materials

Driving Simulator

Experimental sessions were conducted in a Real-Time Technologies (RTI) RDS-1000 driving simulator platform. The driving simulator consists of a quarter vehicle cab with steering wheel, pedals, and a customizable dashboard and center stack touchscreen. Three 65-inch displays provide a 205˚ horizontal field of view and 38˚ vertical field of view. The driving simulator has a 5.1 surround sound audio system to mimic vehicle and environment noise. The motion platform provides three-degrees of freedom (DOF) movement. The RDS-1000 driving simulator continuously record numerous vehicle data including velocity, lateral acceleration, longitudinal acceleration, lane offset, steering angle, brake pedal force and throttle pedal angle, sampled at 60 Hz.

Video Recording System

SimObserver Pro, developed by Real-Time Technologies, was used to record video. Three HD cameras captured the participant’s forward view, foot movements, and hand movements. Videos were recorded at 30 fps. Videos were automatically synced to vehicle data.

Eye Tracker

Due to technical failures, two separate eye trackers were used for this study. The original eye tracker, a head-mounted eye tracker (Applied Science Laboratory) consisted of two cameras and a monocle, mounted on an eyeglass frame. One camera recorded the external scene while the other camera recorded the angle of the participant’s right eye using an infrared light, sampled at 30 Hz. The eye tracker was calibrated such that the movement of the participant’s eye is aligned with the scene view feed. The system superimposes a crosshair representing where the participant's eyes are looking onto each frame of a video of the forward scene. The second eye tracker used was the head-mounted Pupil Core (Pupil Labs). This eye tracker uses two infrared cameras to record both eyes, sampled at 200 Hz. The Pupil Core eye tracker also had a camera that captured the forward road scene. A video file superimposed the participant's gaze position onto the forward view scene. There were no observable or statistical differences in terms of tactical hazard anticipation performance between participants who wore the ASL eye tracker and those who wore the Pupil Core eye tracker (B_{10} = 1/2.67 for inexperienced participants and B_{10} = 1/2.99 for the experienced group).

Simulator Sickness Questionnaires

To minimize the risk of participants experiencing simulator sickness, two simulator sickness questionnaires were administered. The Motion Sickness Susceptibility Questionnaire-Short (MSSQ-Short) (Golding, 1998) was administered before the participants started driving. A previous study examining the validity of the MSSQ-Short indicated that the 75th percentile score is 19 (Golding, 2006). Therefore, 19 points or above on the scale was used as a cutoff point and any person who scored in that range was dismissed. The Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) was administered both before they started the recorded session, after a brief practice drive (to establish a baseline) and after the experimental drives. If participants indicated that they are susceptible to simulator sickness prior to the study or if they demonstrated simulator sickness during the study, or noted that they were starting to feel unwell, they were dismissed.

Driving History Questionnaire

At the end of the study, participants filled out a driving history questionnaire. This questionnaire included both demographic questions (such as age and gender) and elements of the participants' driving history (such as text messaging, time since licensure, miles driven, number of days per week they drive, history of moving violations, and history of vehicle crashes). These variables were used to statistically control for individual differences such as age and miles driven when examining group differences in operational and tactical HA, and crash avoidance.

Driving Scenarios

Participants drove through eight hazard anticipation scenarios; four were environmental hazard scenarios and four were behavioral hazard scenarios. There were four scenario environments (crosswalk, opposing left-turn, right-turning vehicle, or construction zone), with a behavioral and environmental hazard being placed in each environment. Each scenario was approximately 6,000 feet long and took about two to three minutes to complete. The order of the eight hazard anticipation scenarios was randomized for each participant. Ambient traffic was included in the simulator scenarios to prevent cueing the participation to the location of the hazard.

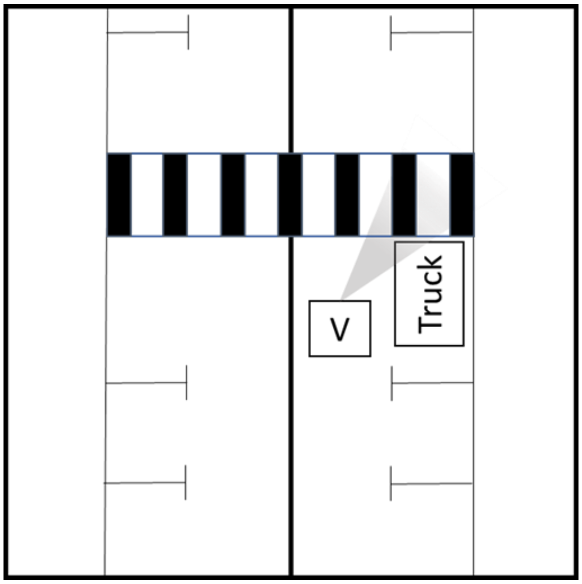
Environmental Hazard Scenarios

Midblock Crosswalk

This scenario took place in a town environment, with cars parallel parked along both sides of the road. In this situation, a large truck obscures the entrance to a crosswalk (Figure 1). The precursor is the truck blocking the view of the crosswalk. The hazard is the pedestrian emerging from behind the truck into the road, but the hazard never materializes.

Figure 1

Truck in crosswalk scenario.

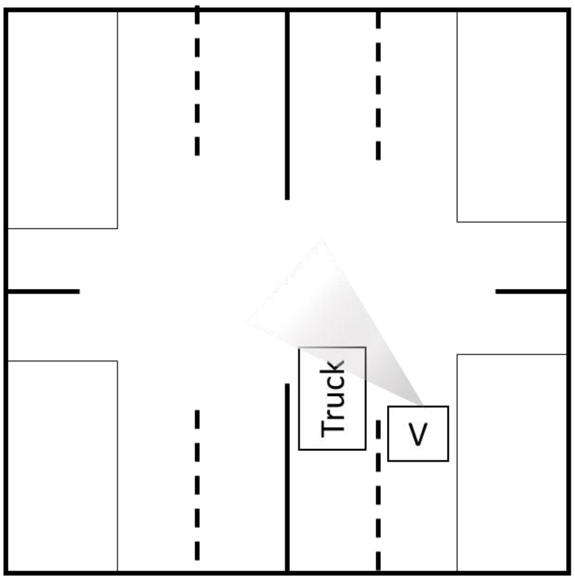


Adjacent Truck Intersection

This scenario involved the participant driving down a divided highway (Figure 2). As they approach an intersection, a truck is in the left-hand lane, waiting to make a left-hand turn, obscuring the view of vehicles coming in the opposite direction. These oncoming vehicles may potentially make a left-hand turn into the participant's path. The precursor is the truck blocking the view of oncoming traffic. The hazard is a vehicle turning into the participant's path, but the hazard never materializes.

Figure 2

Adjacent truck intersection scenario.

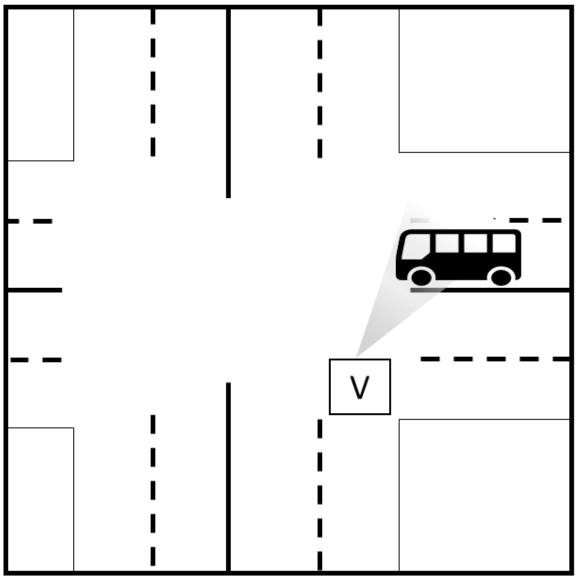


Multiple-lane Intersection with Bus

The participant drives down a four-lane road. As they approach a signal-controlled intersection, they see a bus stopped at the light to the right, in the left lane (Figure 3). This bus is obscuring the view of the right lane, where a vehicle or cyclist may be waiting to make a right-hand turn into the path of the vehicle. The precursor is the bus blocking the view of the right lane. The hazard is the vehicle or cyclist turning into the participant's path, but the hazard never materializes.

Figure 3

Multiple-lane intersection with bus scenario.

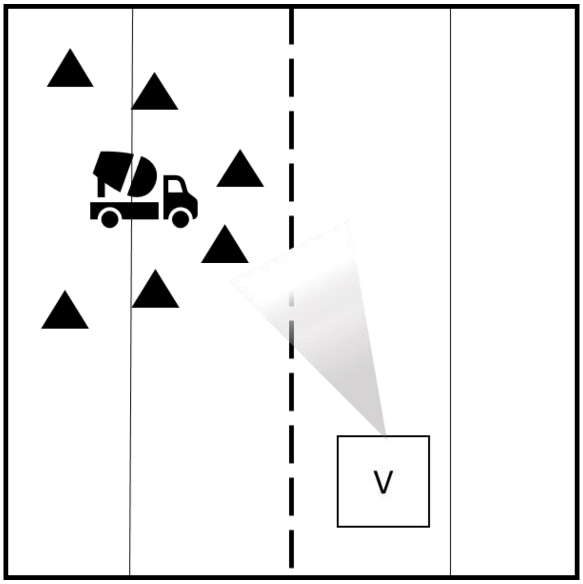


Construction Zone Blocking View of Oncoming Traffic

In this scenario, the participant is traveling down a one-lane road, where they approach a construction zone, blocking the opposing lane (Figure 4). A large construction truck is parked such that the participant cannot see oncoming traffic, which may enter the participant's lane in order to maneuver around the construction zone. The precursor is the construction truck, blocking the view of oncoming traffic. The hazard is the car maneuvering around the construction, but the hazard never materializes.

Figure 4

Construction zone blocking view of oncoming traffic.



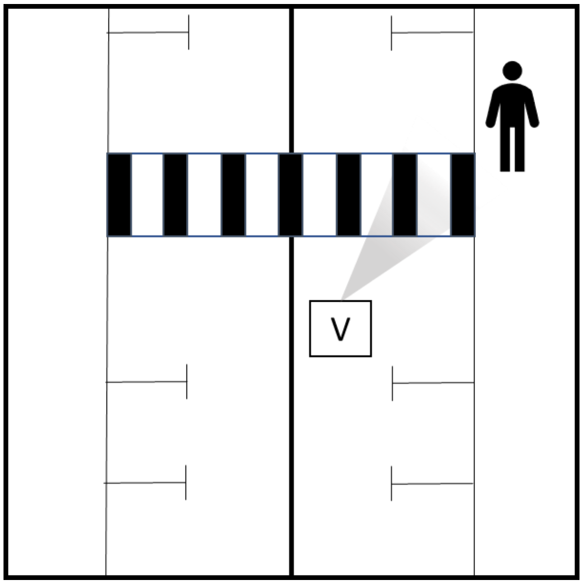
Behavioral Hazard Scenarios

Pedestrian Near Crosswalk

This scenario takes place in a town environment, with cars parked on either side (Figure 5). A pedestrian is on the sidewalk, walking near a crosswalk, but does not enter the crosswalk. The precursor is the pedestrian avatar. The pedestrian never steps into the road.

Figure 5

Pedestrian near crosswalk scenario.

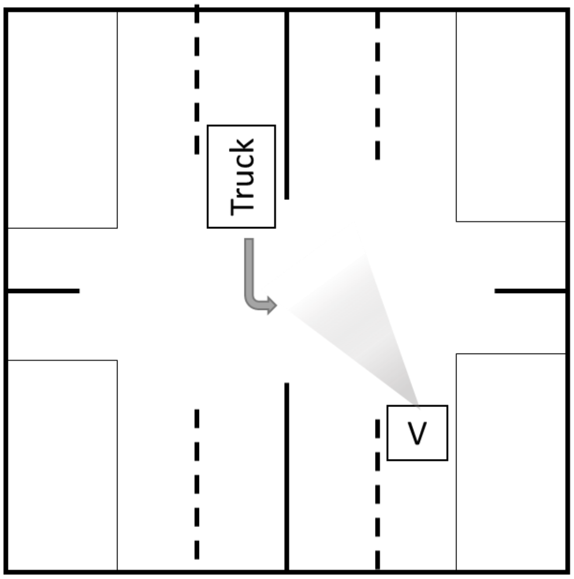


Truck (Vehicle Making Left Turn)

This scenario involves the participant driving down a divided highway (Figure 6). As they approach an intersection, a truck in the opposing lane is waiting to make a left-hand turn, inching into the intersection. The precursor is the vehicle with the turn signal on. The vehicle never turns into the participant's path.

Figure 6

Vehicle making left turn scenario.

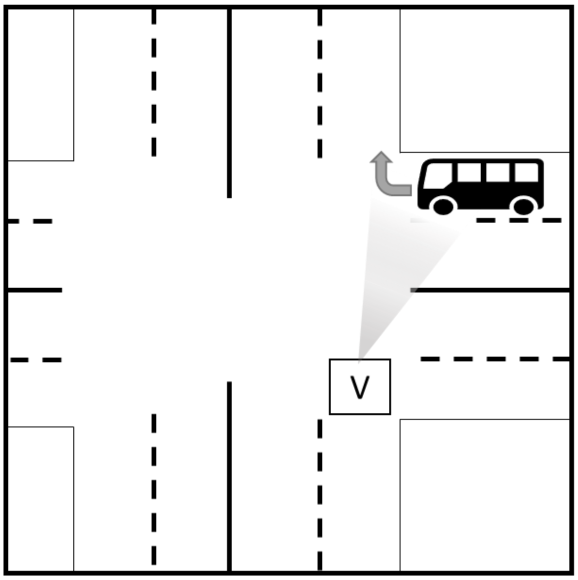


Bus (Vehicle on Right at Intersection)

This scenario takes place at an intersection in a town environment. The participant will approach a signal-controlled intersection with a green light (Figure 7). On their right, a vehicle will slowly enter the intersection to make a right turn on red. The precursor is the vehicle waiting to make a right turn. The vehicle never turns into the intersection in front of the participant.

Figure 7

Vehicle on right at intersection scenario.

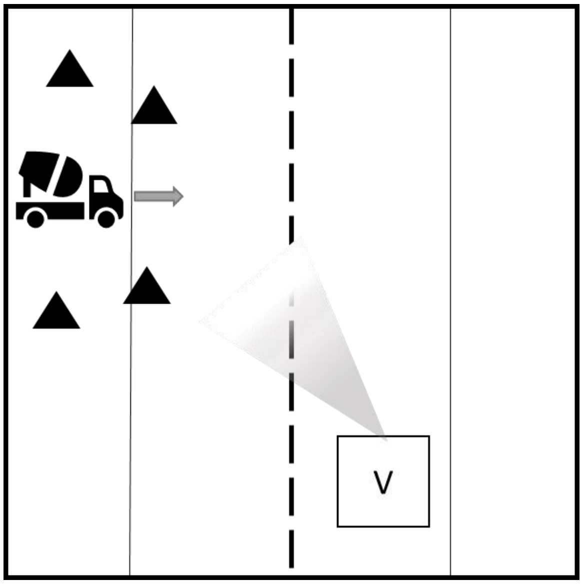


Construction Zone in Opposite Lane

In this scenario, the participant is traveling down a one-way road, where they approach a construction zone. A construction truck is placed on the sidewalk. The truck was inching into the opposing lane, signaling to the participant that the truck might eventually cross the street into their vehicle's path. The precursor is the construction truck. The truck never crosses the street in front of the participant.

Figure 8

Construction zone in opposite lane.



Crash Avoidance Scenario

After all eight hazard scenarios were completed, participants received a final crash avoidance (CA) scenario. The scenario was identical to the Truck scenarios (Figure 2 and Figure 6), except a hazard did materialize. In order to avoid colliding with the vehicle, the participant needed to engage in hazard mitigation behaviors (either swerving or braking). Half of participants had to avoid a behavioral hazard (Figure 6). In this hazard, the truck which had previously inched forward, but stopped short of intersecting with the participant's driving path, did eventually cross in front of the participant. In this scenario, the precursor to the hazard was apparent, and if participants assumed that the moving truck would eventually cross in from of them, they were given sufficient time to slowly come to a complete stop to avoid the hazard. The environmental CA scenario was more difficult to avoid, as a vehicle appeared suddenly from a blind zone caused by a row of trucks waiting to make a left-hand turn (Figure 2). Avoiding the vehicle that was making a left-hand turn from the opposing lane into the participant's path, required almost immediate action by the participant.

Dependent Measures

Tactical Latent HA Score

This score is the proportion of scenarios that the participant correctly anticipated the location of the latent hazard (out of eight scenarios). A "successful" anticipation is a glance towards the area of interest within the target zone. These zones were defined *a priori* to ensure proper and consistent coding. This protocol has been used in previous studies on HA (Unverricht et al., 2018) and have demonstrated moderate to high interrater reliability (Plumert et al., 2021). Tactical HA has been shown to have high ecological validity, with results from on-road studies replicating results found in the driving simulator (Fisher et al., 2007). The measure of tactical HA as an eye movement was developed specifically to determine if drivers fixated on areas that were risky and may contain hazards and to be judged by a coder familiar with the concept (Pradhan et al., 2005) demonstrating high construct validity. A driver's fixation to an area where a hazard may appear is not a guarantee that said driver has indeed anticipated the hazard (e.g., they may have unrelatedly fixated on the area as they were scanning). However, differences in fixation patterns between experienced and inexperienced drivers suggest that fixating to a risky area is at least related to anticipating the hazard that may be present (Pradhan et al.., 2005), suggesting content validity. Finally, considering the close relationship between the measure of tactical HA (fixation on an area of a hazard) and the behavior it seeks to measure (fixating on a hazard to indicate anticipation of a hazard), tactical HA also demonstrates face validity.

Operational HA Measure

Video of possible operational hazard anticipation actions were recorded and manually coded. Approximately 7 seconds prior to the participant passing the hazard location was coded. A participant was classified as engaging in operational hazard anticipation if they were shown to either completely release their foot from the accelerator or hover their foot over the brake. If a participant hovered their foot over the brake before pressing the brake pedal, it was counted as an operational hazard engagement. However, if the participant immediately shifted from the accelerator to the brake, it was not classified as operational hazard anticipation as such sudden movements would not suggest behavioral preparation. Change in steering wheel grip position was originally proposed as a possible measure of operational hazard anticipation. However, this sort of movement was only observed in 4 out of 359 possible trials. Therefore, in the context of this study and the following results, “operational HA” means the participant hovered their foot over the accelerator or the brake at some point when approaching the hazard.

Hazard Mitigation

Driving behavior measures, velocity (mph), longitudinal acceleration (m/s^2), lateral acceleration (m/s^2), throttle pedal angle (degrees), brake force (N), lane offset (m), and steering wheel angle (radians) were used to determine if participants were engaging in HM techniques when approaching the hazards.

Crash Avoidance Performance

Crash avoidance performance was binary coded as either a “success” or a “failure”. If participants collided with the opposing vehicle in the driving simulator; CA was a “failure”; if they avoided colliding with the opposing vehicle, the CA was a “success”.

CHAPTER VIII

RESULTS

Data Reduction, Cleaning, and Processing

Data were submitted to two 2 × 2 mixed Bayesian Analyses of Variance (ANOVAs) to examine differences in tactical and operational HA performance between experience group (between-subjects factor) and scenario type (within-subjects factor). Interactions were investigated with follow-up Bayesian t-tests. In addition, logistic regression was used to investigate if operational and tactical HA performance could predict a participant's success or failure at avoiding the hazard in the final scenario. Multiple linear regression was used to investigate if demographic and driving experience factors were related to a participant's average tactical HA and operational HA score.

Evidence from Bayesian analyses is reported below. Bayesian analysis allows testing both for and against the effect of interest, going beyond the capabilities of traditional null hypothesis significance testing. Bayesian analysis tests the likelihood that the alternative hypothesis is true against the likelihood that the null hypothesis is true. The Bayes factor is reported as a measure of evidence (Jarosz & Wiley, 2014) which is the ratio between the likelihood that obtained data contain the effect of interest to the likelihood that the data do not contain the effect of interest. To assess the evidence, guidance suggested by Jeffreys (1961) was used: a Bayes factor between 1 - 3 provide anecdotal evidence for an effect, 3-10 provide substantial evidence, 10-30 provide strong evidence, 30-100 provide very strong evidence, and > 100 provide decisive evidence. For the logistic and linear regressions, Bayesian parameter estimation was used which utilized Markov chain Monte Carlo (MCMC) sampling. Weakly informed priors were used, with 10,000 iterations for each of the first two “warm-up” chains and the two post-warmup chains. 90% Bayesian credible intervals (BCI) were calculated to assess each parameter in the model. BCIs give an estimated range of where 90% of the posterior density lies. Unlike in frequentist methodology, where 95% confidence intervals are the standard, in Bayesian analysis, 90% credible intervals are recommended (Goodrich et al., 2022).

Failures in eye tracking and one failure of the driving simulator recording resulted in seven instances of data loss (four trials in the inexperienced group and 3 trials in the experienced group), which resulted in 2.2% of data being excluded.

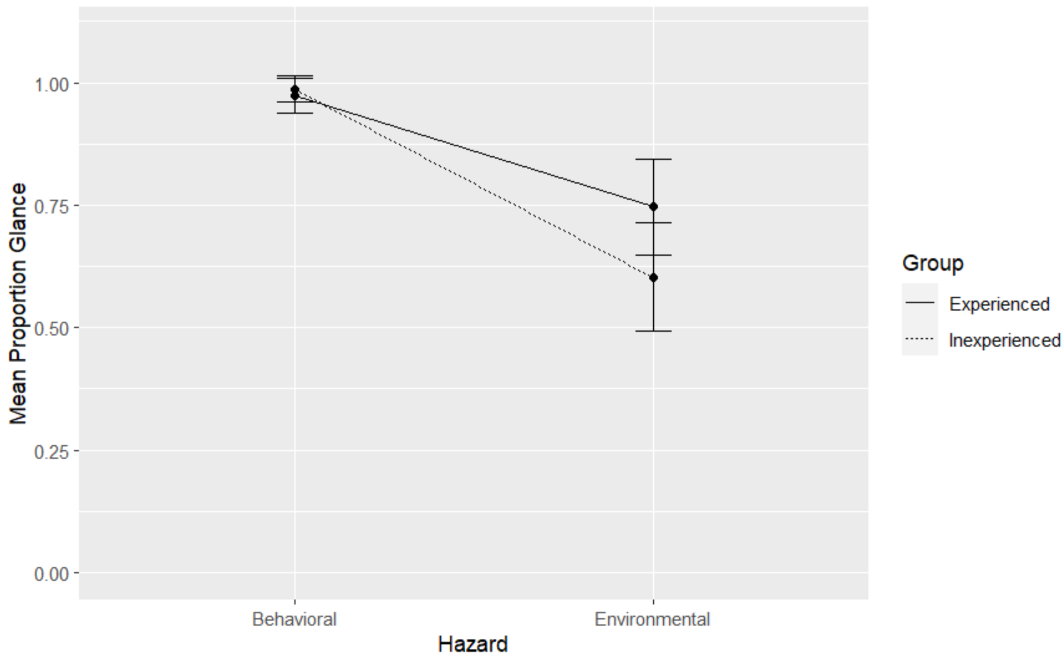
Driving behavior data were collected in the driving simulator at a rate of 60 Hz. Only data from the 10 seconds the participant was driving prior to the location of the hazard in the simulator were analyzed. Data were averaged at one second increments to create 10 one-second epochs. Seven variables were analyzed: velocity (mph), longitudinal acceleration (m/s^2), lateral acceleration (m/s^2, with negative values indicating movement to the left), throttle pedal angle (degrees between 0-90, with 0 indicating no throttle press), brake force (value between 0-170, representing newtons), lane offset (meters from the center of the lane (positive values are to right of center, negative values are to the left), and steering wheel angle (in radians, with negative values indicating steering to the left). An exploratory 10 (Second) × 2 (Group) ANOVA was conducted on the driving behavior variables for each scenario, followed by post-hoc Bayesian t-tests. The purpose of these exploratory analyses was to examine potential differences more closely in driving mitigation behavior between experienced and inexperienced drivers (e.g., Muttart, 2013; Yamani et al., 2016). In addition, recording driving behavior measures allowed for the potential identification of behaviors that occur in conjunction with operational HA by group. For example, the throttle pedal angle may reflect a driver’s engagement in operational HA behavior due to them completely releasing the throttle in order to hover their foot over the brake pedal.

Tactical Hazard Anticipation

Figure 9 illustrates the mean tactical hazard anticipation score for experienced and inexperienced drivers, by hazard type (behavioral or environmental). Descriptive statistics are provided in Table 1. Tactical HA scores were submitted to a 2 x 2 mixed Bayesian ANOVA with group (inexperienced vs. experienced) as a between-subject factor and hazard type (behavioral vs. environmental) as a within-subject factor. Data indicated a decisive effect of hazard type, $F(1, 38) = 71.80$, $B_{10} = 1.28 \times 10^{10}$, $\eta^2_G = 0.49$, showing that drivers anticipated hazards correctly in more behavioral than tactical scenarios ($M = .981$, $SD = .137$ vs. $M = .675$, $SD = .469$, respectively). However, the data showed no substantial support for the presence of the remaining effects, both $B_{10} < 1.92$.

Figure 9

Mean tactical anticipation performance by hazard type. Error bars represent 95% confidence intervals.



Operational Hazard Anticipation

Figure 10 illustrates the mean operational hazard anticipation score for experienced and inexperienced drivers, by hazard type (behavioral or environmental). Operational HA scores were submitted to a 2 x 2 mixed Bayesian ANOVA with group (inexperienced vs. experienced) as a between-subject factor and hazard type (behavioral vs. environmental) as a within-subject factor. Data provided substantial evidence for the presence of the main effect of group, $F(1, 38) = 4.27$, $B_{10} = 3.13$, $\eta^2_G = 0.075$, suggesting that experienced drivers anticipated hazard correctly in more scenarios than young drivers ($M = .350$, $SD = .479$, vs. $M = .192$, $SD = .395$ respectively). Furthermore, data indicated very strong evidence that drivers correctly anticipated behavioral hazards more (M = .385, SD =.488) than environmental hazards (M = .159, SD = .367), $F(1, 38) = 21.86$, $B_{10} = 38.46$, $\eta^2_G = 0.137$. Data gave substantial evidence against the presence of an interaction between group and hazard type, $F(1, 38) = 0.02$ $B_{10} = 1/3.28$, η^2_G <.001.

Figure 10

Mean operational hazard anticipation score by hazard type. Error bars represent 95% confidence intervals.

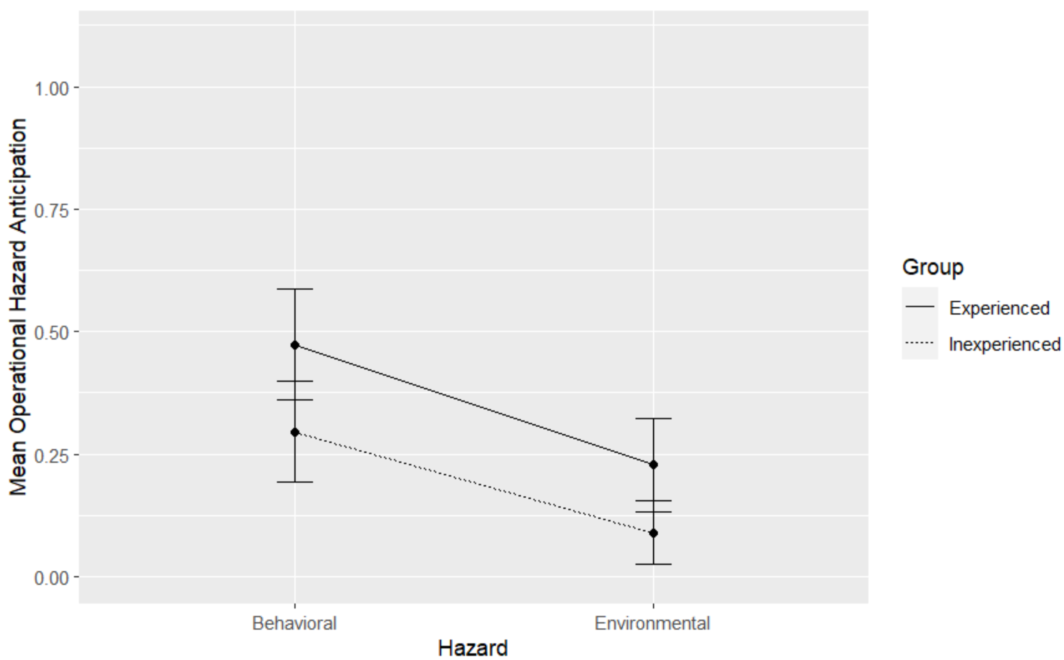


Table 1

Descriptive statistics for Tactical HA and Operational HA.

		Tactical HA		Operational HA	
Group	*Hazard Type*	*M*	*SD*	*M*	*SD*
Experienced	Behavioral	.974	.159	.474	.503
Experienced	Environmental	.747	.438	.228	.422
Inexperienced	Behavioral	.987	.113	.295	.459
Inexperienced	Environmental	.603	.493	.090	.288

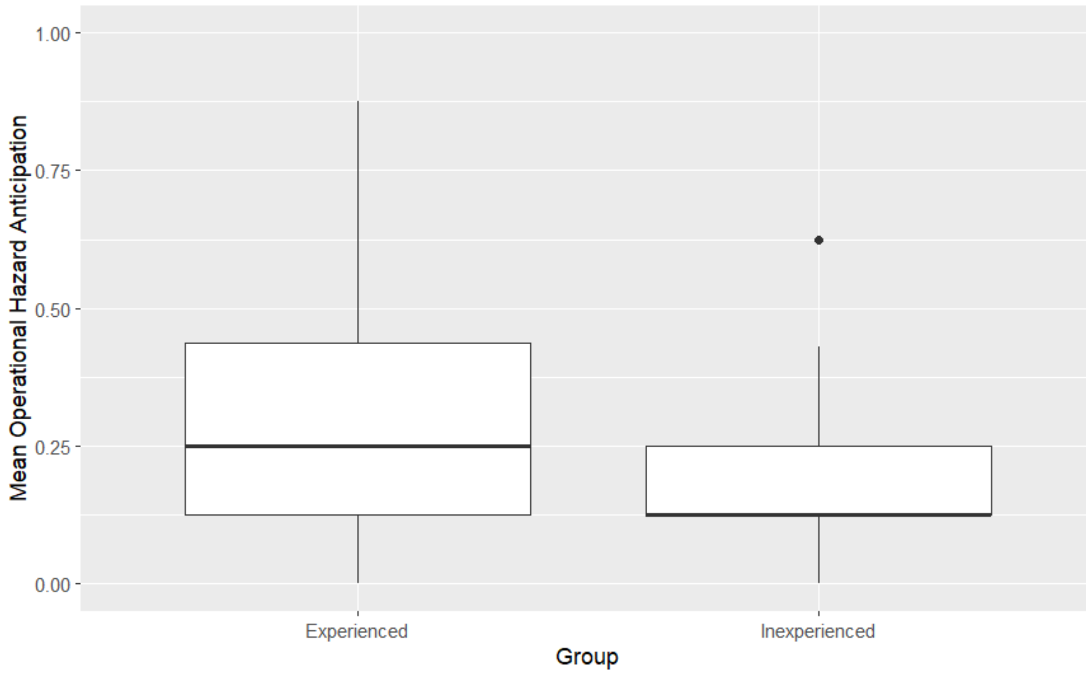
Relationships Between Tactical and Operational HA

A Pearson correlation was calculated between mean tactical HA score and mean operational HA score to investigate the relationship between the two concepts. However, data only showed anecdotal evidence to suggest that a participant's tactical HA and operational HA scores are related, r = .268, B_{10} = 1.20.

When examining the data, there appeared to be a wide range of individual differences amongst participants in their decision to engage in operational hazard anticipation behaviors. For example, seven participants did not demonstrate any operational HA behavior when approaching the hazards. On the other hand, four participants engaged in HA behavior in 75% or more of the simulator drives. Figure 11 shows the distribution of individuals' average operational HA score by group, with the experienced group showing a wider range of possible scores.

Figure 11

Distribution of individual participants' mean operational hazard anticipation scores.



To investigate the possible influences of demographics and driving history on operational HA score, participants' gender, age, months since licensure, days per week they drive, report of moving violations in the past three years (yes or no), and report of vehicle crashes in the past three years (yes or no) were submitted to a multiple linear regression. None of the factors tested were related to an individual's operational HA score, slopes ≤ 0.1.

Hazard Mitigation

For exposition, the velocity plot for each scenario is included. In addition, an exploratory 10 (second) x 2 (group) ANOVA was conducted for each variable in every scenario. If the ANOVAs suggested a substantial effect, the plot is included, and post-hoc tests were performed.

Table 2 provides a summary of substantial main effects of group found in the exploratory analyses. Velocity, throttle pedal position, and lane offset position were the three variables where differences between the experienced and inexperienced groups emerged. In four out of five cases, participants in the experienced group drove more slowly during the 10 seconds before passing the hazard compared to the inexperienced group. In all five instances of group differences in lane offset, experienced participants drove in a way where they were further from the hazard compared to inexperienced participants. However, experienced participants also depressed the throttle pedal more compared to inexperienced participants in the two instances where there were group differences.

Table 2

Substantial main effects of group for driving behavior data.

		Velocity	Throttle	Lane offset
Environmental	Bus			B_{10} = 71.42 (*M* = -0.18 vs. -0.10 meters)
	Truck	-		B_{10} = 1.30 x 10^6 (*M* = 0.03 vs. -0.09 meters)
	Construction	B_{10} = 3,225.80 (*M* = 31.92 vs. 34.27 mph)		
	Midblock crosswalk	B_{10} = 8.65 (*M* = 28.85 vs. 30.29 mph)		B_{10} = 3.48 x 10^{19} (*M* = -0.31 vs. -0.06 meters)
Behavioral	Bus	B_{10} = 625.00 (*M* = 34.39 vs. 36.63 mph)		
	Truck	B_{10} = 297.62 (*M* = 36.29 vs. 33.67 mph)		
	Construction	B_{10} = 452.49 (*M* = 20.26 vs. 24.05 mph)	B_{10} = 2500.00 (*M* = 8.64 vs. 6.35 degrees)	B_{10} = 23.80 (*M* = 0.39 vs. 0.32 meters)
	Midblock crosswalk		B_{10} = 4.12 (*M* = 5.18 vs. 4.07 degrees)	B_{10} = 4,424.78 (*M* = -0.20 vs. -0.10 meters)

Note. Green shading indicates where experienced group exhibited safer hazard mitigation behaviors. Yellow shading indicates where inexperienced drivers exhibited safer hazard mitigation behaviors.

Table 3 provides a summary of substantial main effects on time found in the exploratory hazard mitigation analyses. There were six driving behavior variables where differences over time emerged: longitudinal acceleration, lateral acceleration, throttle, brake, lane offset, and steering.

Table 3

Substantial main effects of second for driving behavior data.

		Longitudinal acceleration	Lateral acceleration	Throttle	Brake	Lane offset	Steer
Environmental	Bus						
	Truck		B_{10} = 8.85 7 vs. 2 sec (*M* =0.007 v. -0.034)			B_{10} = 4.55 x 10^6 10, 9, 8 vs 3, 2, 1 sec (*M* = -0.18, -0.15, -0.11 vs. 0.07, 0.08, 0.06)	B_{10} = 5.10 7 vs. 3 sec (*M* = 0.002 vs. -0.010)
	Construction			B_{10} = 4.26 2 vs. 10 sec (*M* = 8.00 vs. 5.59)			
Behavioral	Bus			B_{10} = 6,250 1 vs. 8, 7, 6, 5, 4, 3 sec (*M* = 10.17 vs. 7.12, 6.57, 6.50, 5.83, 5.31, 6.10)		B_{10} = 33.33 1 vs. 2, 3 sec (*M* = -0.025 vs.-0.292, -0.243)	
	Truck			B_{10} = 1,754.39 1 vs. 3, 4, 5, 6, 7, 8, 9, 10 (*M* = 8.86 vs. 4.99, 5.07, 5.47, 5.76, 5.91, 5.78, 5.57, 5.31)			
	Construction	B_{10} = 18,857.19 10, 9 vs. 1, 2 sec (*M* = -0.76, -0.62 vs. 0.63, 0.44)		B_{10} = 9.08 x 10^{24} 10, 9, 8, 7, 6, 5 vs. 2, 1 sec (*M* = 2.96, 3.09, 4.49, 5.40, 6.76, 7.76 vs. 11.59, 12.94)	B_{10} = 8.27 10 vs. 1 sec (*M* = 11.04 vs. 0.02)	B_{10} = 2.99 x 10^6 10, 9, 8, 7, 6, 5, vs. 1 sec (*M* = 0.250, 0.275, 0.297, 0.317, 0.336, 0.354 vs. 0.497)	
	Midblock crosswalk	B_{10} = 53,713.00 1 vs. 7, 8, 9, 10 sec (*M* = 0.67 vs. 0.39, -0.70, -0.68, -0.51)		B_{10} = 5.32 x 10^{18} 1 vs. 3, 4, 5, 6, 7, 8, 9, 10 sec (*M* = 9.92 vs. 5.69, 5.00, 4.22, 3.27, 2.74, 2.60, 2.51, 2.64)	B_{10} = 28.54 3 vs. 8 sec (*M*=1.98 vs. 14.77)		

Table 4 describes the two interaction effects between time and group found in the exploratory analyses. Interaction effects were found in two variables: throttle pedal depression and steering angle.

Table 4

Substantial interaction effects for driving behavior data.

		Throttle	Steer
Environmental	Bus		
	Truck		
	Construction		
	Midblock crosswalk		
Behavioral	Bus	B_{10} = 14.99 Experienced (M = 12.67) vs. inexperienced (M = 7.66) at 1 sec	
	Truck		
	Construction		B_{10} = 8.67 Experienced (M = 0.019) vs. inexperienced (M = -0.006) at 4 sec Experienced (M = -0.022) vs. inexperienced (M = 0.008) at 1 sec
	Midblock crosswalk		

Environmental Hazard Scenarios

Bus. There was a very strong main effect of group on lane offset position, $F(1, 38)$ = 1.80, B_{10} = 71.42, η^2_G = 0.033. A follow-up t-test revealed strong evidence that experienced drivers drove more to the left (M = -0.18), further from the bus hazard, than inexperienced drivers (M = -0.10), $t(398)$ = -3.63, B_{10} = 59.93.

Figure 12

Mean velocity (mph) for the bus-environmental scenario.

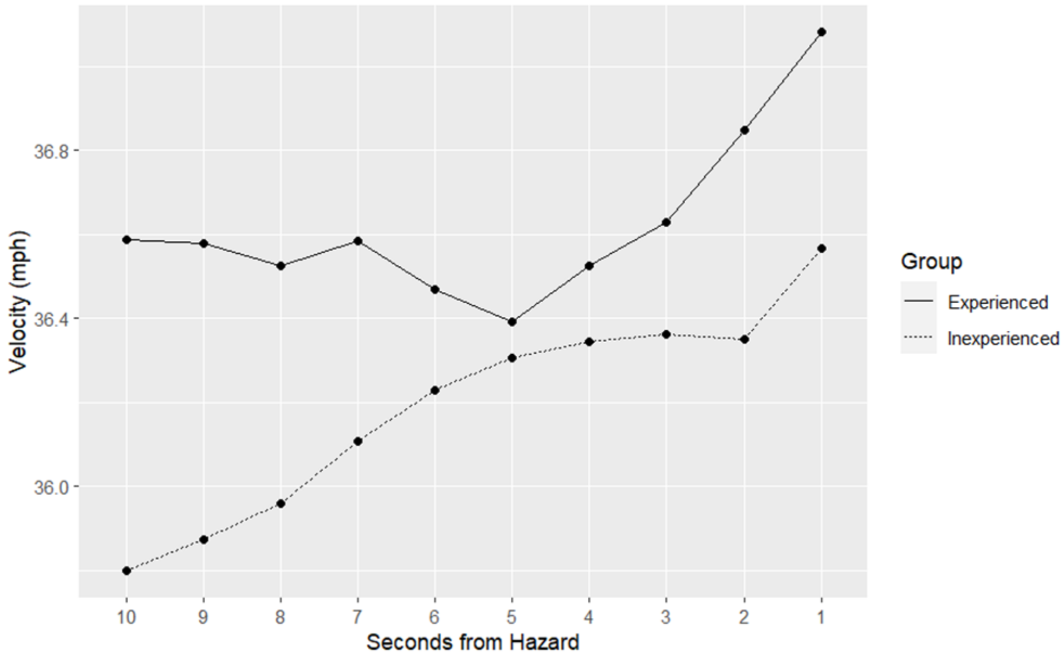
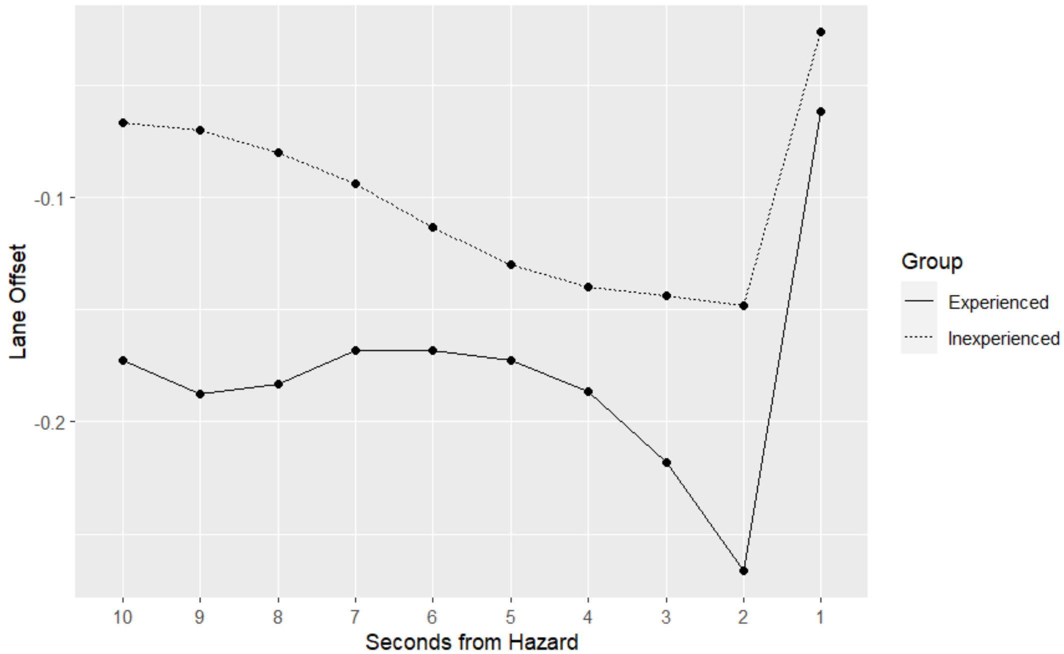


Figure 13

Lane offset (in meters) for truck-environmental scenario.



Note. In this scenario, the more negative the value, the further away the vehicle was from the truck hazard.

Truck. There was a decisive main effect of time on lane offset position, $F(1.95, 74.23) = 44.94$, $B_{10} = 4.55 \times 10^6$, $\eta^2_G = 0.066$. Compared to at 10 (M = -0.18), 9 seconds (M = -0.15, and 8 seconds (M = -0.11) before the hazard, participants drove further to the right (further from the hazard) at 3 (M = 0.07), 2 (M = 0.08), and 1 (M = 0.06) seconds before the hazard (Figure 15). There was also a decisive main effect of group on lane offset, $F(1, 38) = 11.55$, $B_{10} = 1.30 \times 10^6$, $\eta^2_G = 0.005$. Experienced drivers drove decisively more to the right (M = 0.03), further from the truck hazard, compared to inexperienced drivers (M = -0.09), $t(398) = 5.12$, $B_{10} = 24621.28$.

Figure 14

Mean velocity (mph) for the truck-environmental scenario.

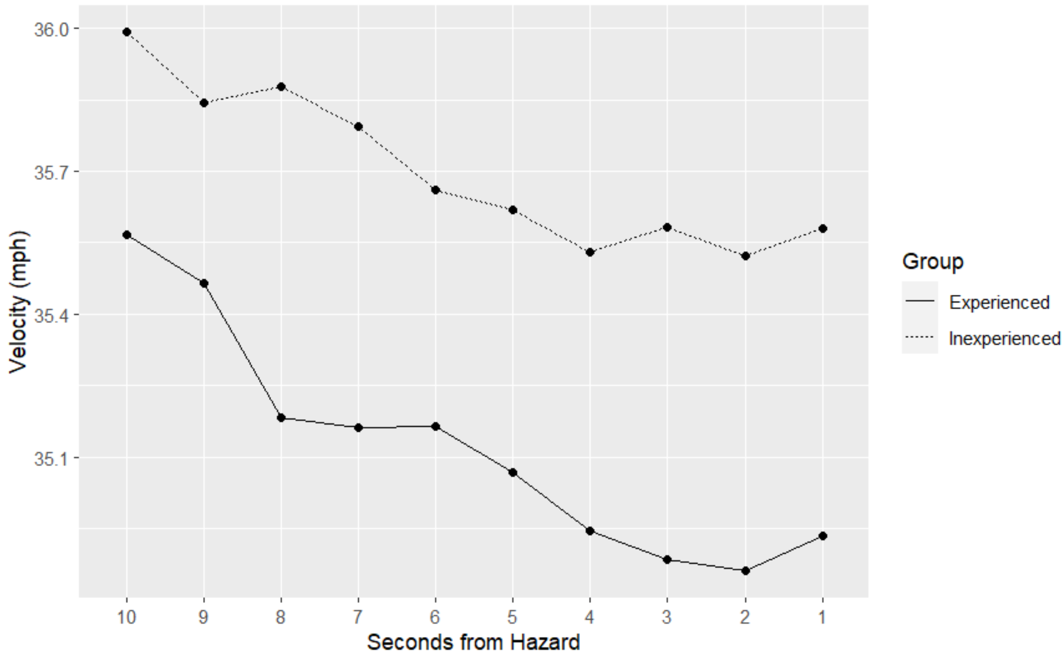
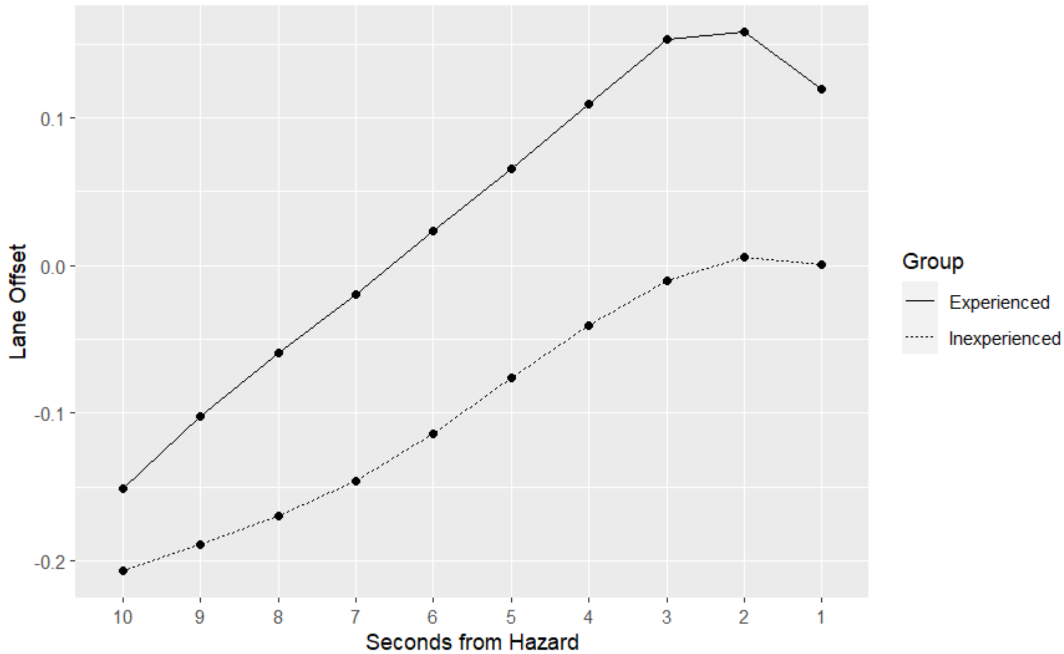


Figure 15

Lane offset (in meters) for truck-environmental scenario.

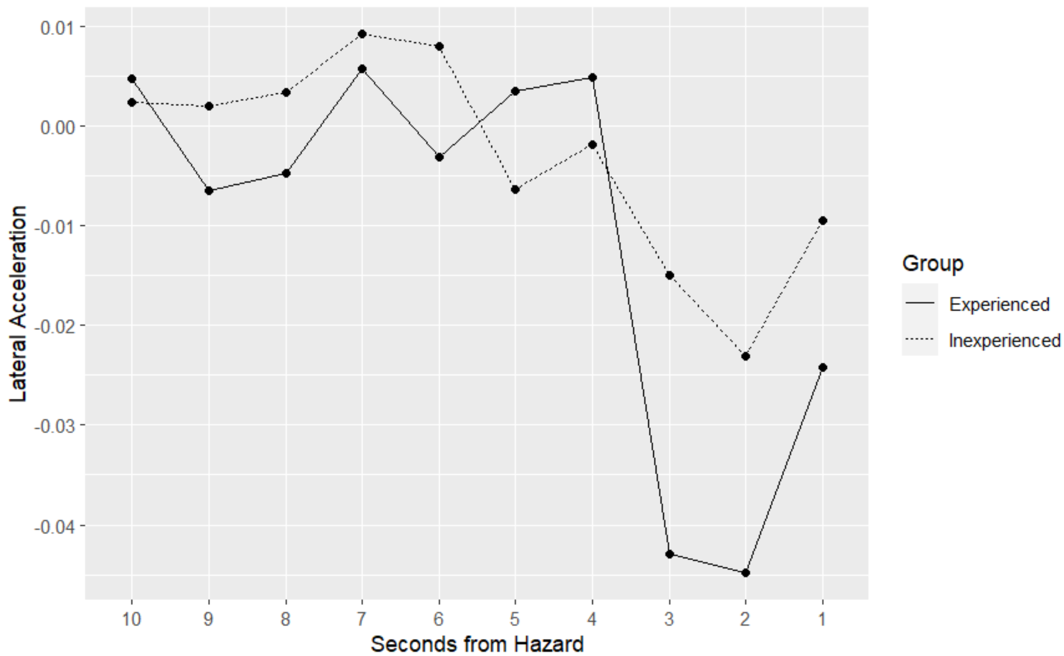


Note. In this scenario, the more positive the value, the further away the vehicle was from the truck hazard.

There was a substantial main effect of seconds on lateral acceleration, $F(4.10, 155.85) = 2.72$, $B_{10} = 8.85$, $\eta^2_G = 0.066$. There was a difference between 7 seconds (M =0.007) and 2 seconds (M = -0.034), where drivers shifted toward the hazard at two seconds (Figure 16).

Figure 16

Lateral acceleration (m/s^2) for truck-environmental scenario.

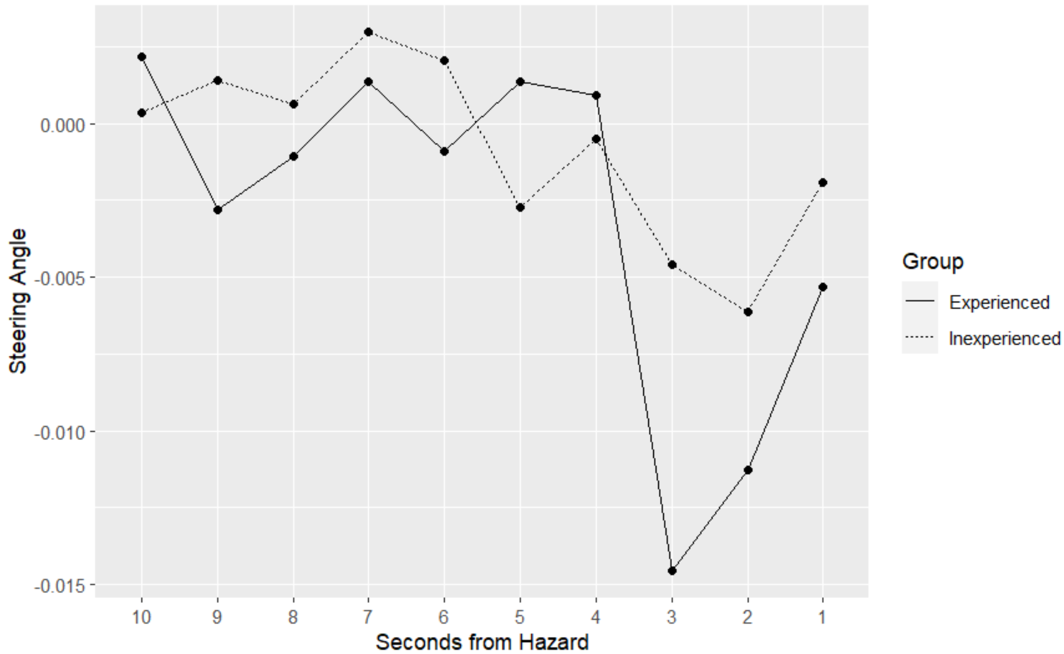


Note. Negative values indicate movement towards the truck hazard.

There was a substantial main effect of seconds on steering angle, $F(4.08, 155.19) = 2.59$, $B_{10} = 5.10$, $\eta^2_G = 0.063$, with steering angle more to the right at 7 seconds ($M = 0.002$) compared to 3 seconds ($M = -0.010$) before the hazard (Figure 17).

Figure 17

Steering angle in truck-environmental scenario.

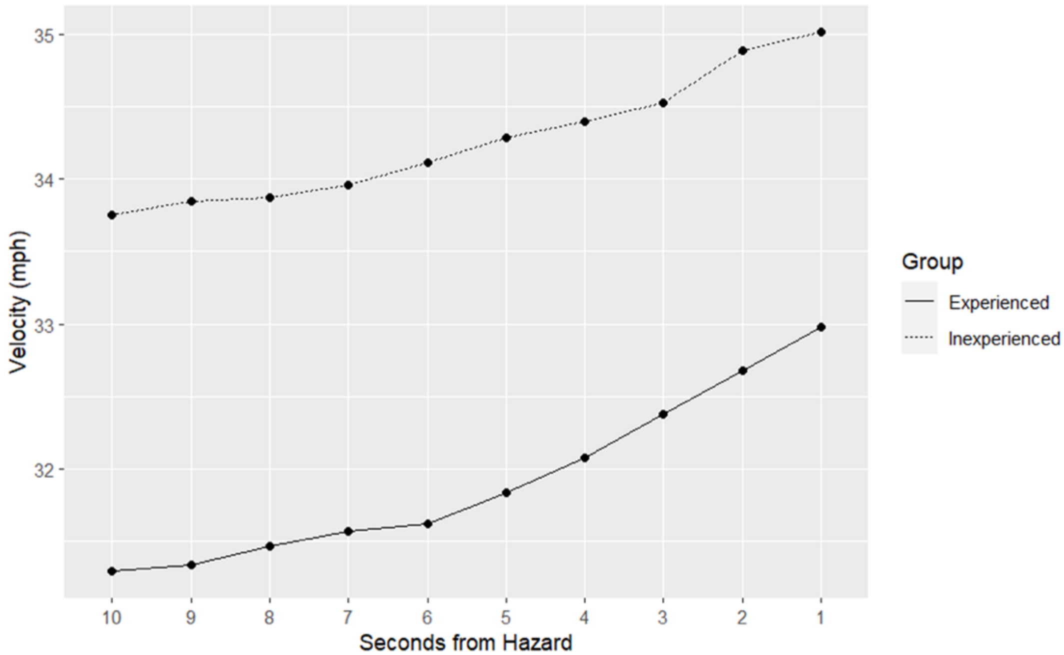


Note. Negative value indicates turning to the left, toward the truck hazard.

Construction. There was a decisive main effect of group on velocity, $F(1, 38) = 2.80$, $B_{10} = 3{,}225.80$, $\eta^2_G = .052$. Experienced drivers drove decisively slower ($M = 31.92$) than inexperienced drivers ($M = 34.27$) in the 10 seconds before the construction hazard, $t(398) = -4.65$, $B_{10} = 2966.43$ (Figure 18).

Figure 18

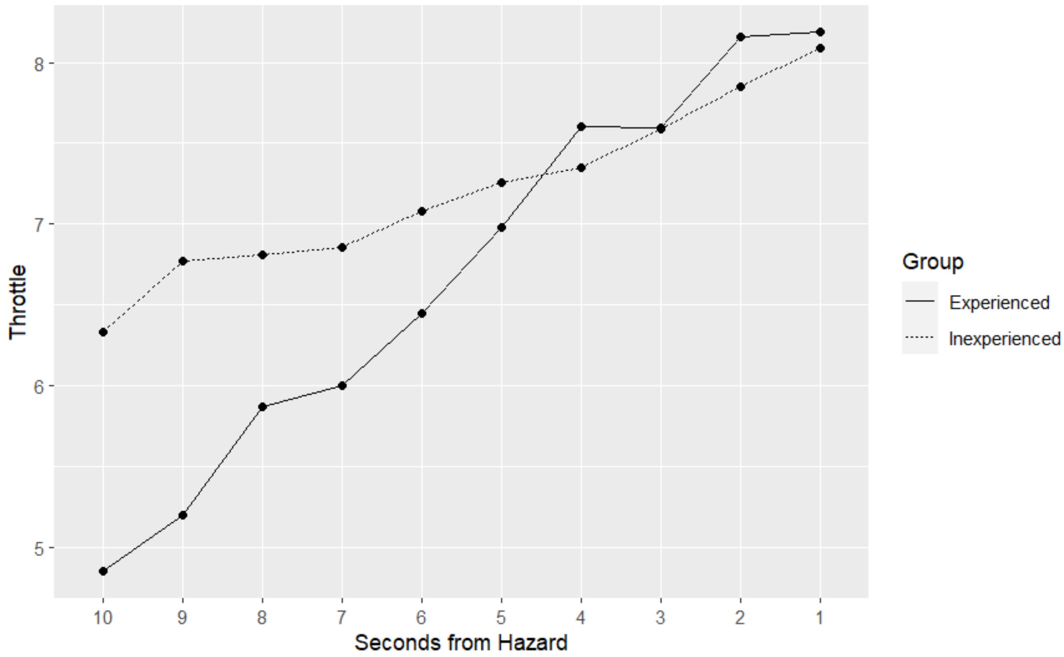
Mean velocity (mph) for the construction-environmental scenario.



There was a substantial main effect of seconds on throttle pedal position, $F(2.30, 87.50) = 11.65$, $B_{10} = 4.26$, $\eta^2_G = 0.061$. Participants at 2 ($M = 8.00$) seconds before the hazard depressed the pedal more compared to at 10 seconds ($M = 5.59$) before the hazard (Figure 19).

Figure 19

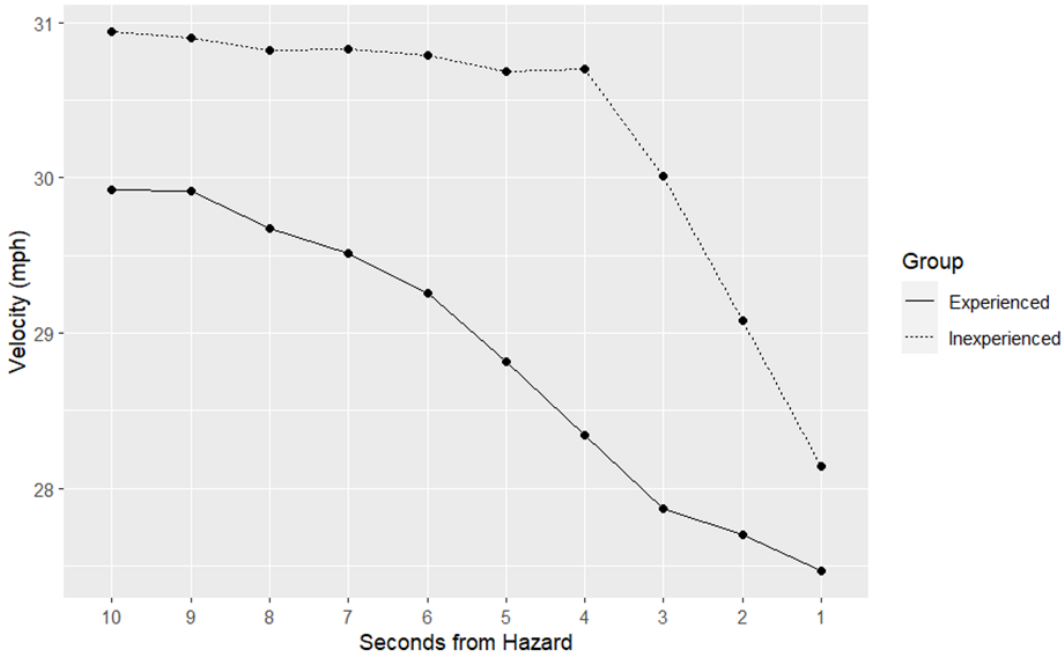
Mean throttle pedal position for construction-environmental scenario.



Midblock Crosswalk. There was a substantial main effect of group on velocity, $F(1, 38) = 1.05$, $B_{10} = 8.65$, $\eta^2_G = 0.023$ (Figure 20). Experienced drivers drove substantially slower ($M = 28.85$) than inexperienced drivers ($M = 30.29$) in the 10 seconds before the construction hazard, $t(398) = -2.99$, $B_{10} = 7.93$.

Figure 20

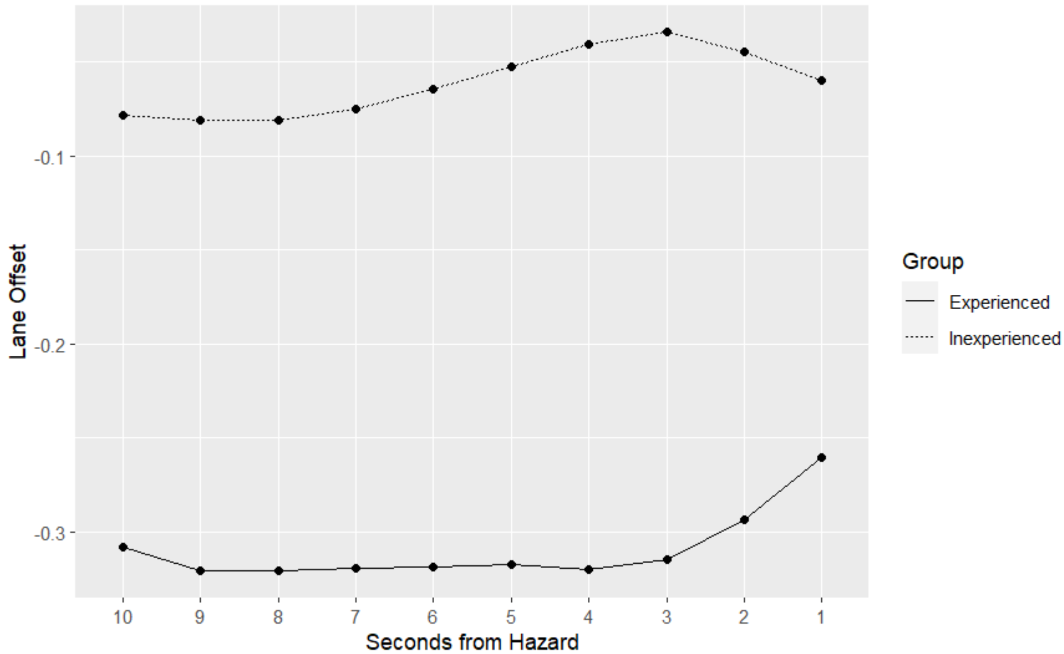
Mean velocity (mph) for the midblock crosswalk-environmental scenario.



There was a decisive main effect of group on lane offset position, $F(1, 38) = 12.18$, $B_{10} = 3.48 \times 10^{19}$, $\eta^2_G = 0.216$ (Figure 21). Experienced drivers drove decisively more to the left ($M = -0.31$), further from the midblock-crosswalk hazard, compared to inexperienced drivers ($M = -0.06$), $t(398) = -10.43$, $B_{10} = 3.21 \times 10^{19}$.

Figure 21

Lane offset (in meters) for midblock crosswalk-environmental scenario.



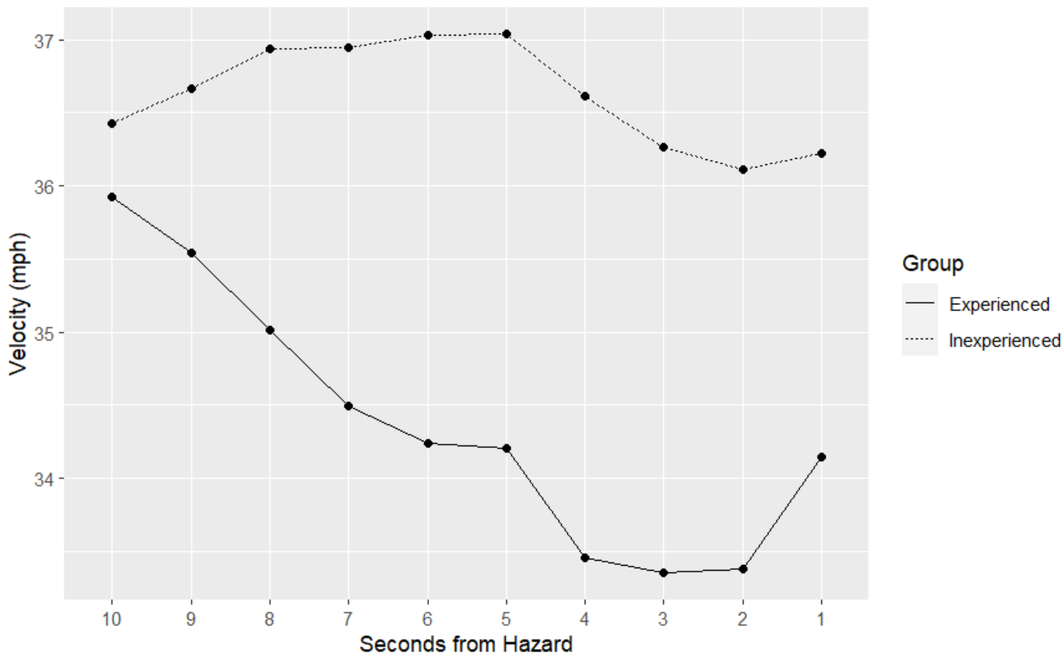
Note. In this scenario, the more negative the value, the further away the vehicle was from the crosswalk hazard.

Behavioral hazard scenarios

Bus. There was a decisive main effect of group on velocity, $F(1, 38) = 2.07$, $B_{10} = 625.00$, $\eta^2_G = 0.044$ (Figure 22). Experienced drivers drove decisively slower ($M = 34.38$) than inexperienced drivers ($M = 36.63$) in the 10 seconds before the construction hazard, $t(398) = -4.24$, $B_{10} = 552.90$.

Figure 22

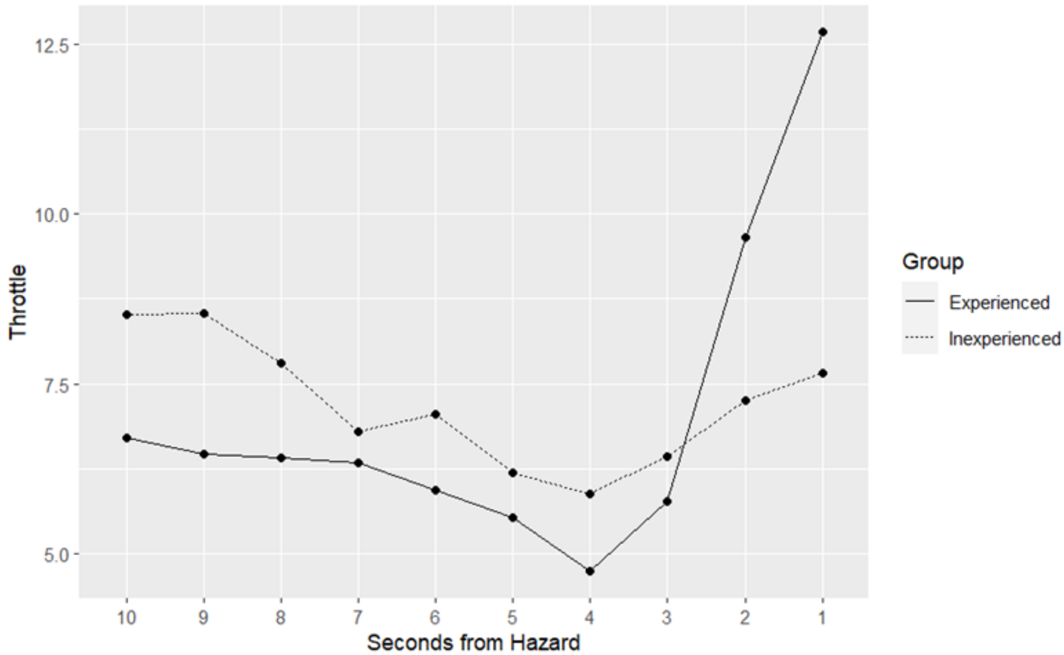
Mean velocity (mph) for bus-behavioral scenario.



There was an interaction between group and second on throttle such that the experienced group demonstrated higher depression on the throttle pedal at 1 second before the hazard (*M* = 12.67) compared to the inexperienced group (*M* = 7.66), $F(3.27, 124.15) = 5.27$, $B_{10} = 14.99$, $\eta^2_G = 0.067$ (Figure 23). There was also a decisive main effect of seconds on throttle pedal position, $F(3.27, 124.15) = 8.71$, $B_{10} = 6{,}250$, $\eta^2_G = 0.106$. Participants depressed the throttle pedal more at 1 second to impact (*M* = 10.17) compared to at 8 (*M* = 7.12), 7 (*M* = 6.57), 6 (*M* = 6.50), 5 (*M* = 5.83), 4 (*M* = 5.31), or 3 (*M* = 6.10), seconds before the hazard.

Figure 23

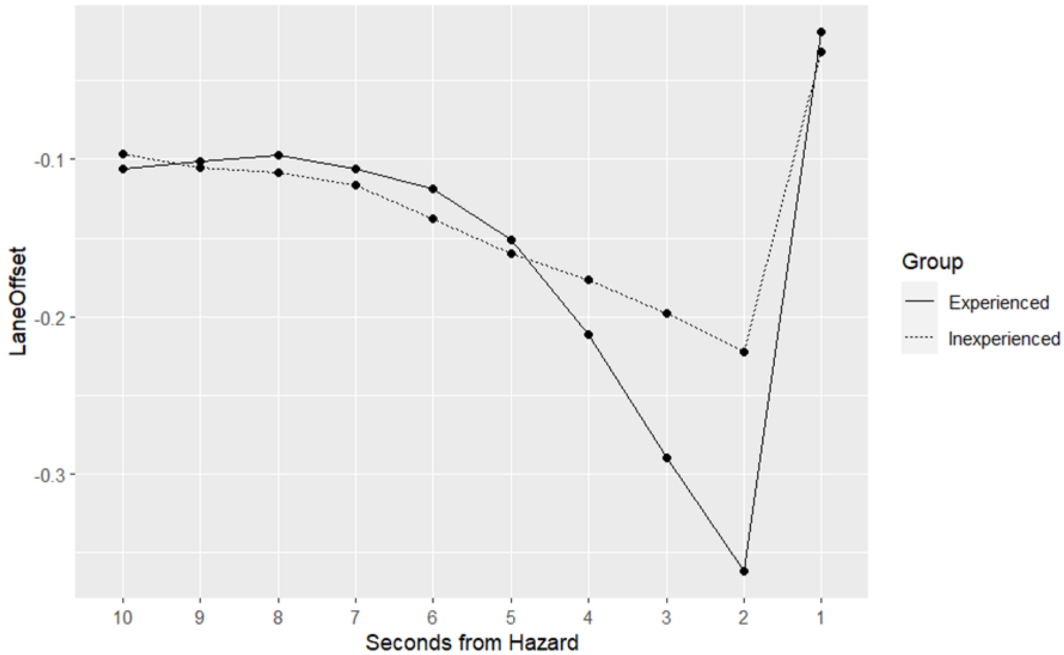
Mean throttle pedal position (degrees) for bus-behavioral scenario.



There was a strong main effect of second on lane offset position, $F(2.62, 99.40) = 11.33$, $B_{10} = 33.33$, $\eta^2_G = 0.074$ (Figure 24). Participants at 1 second ($M = -0.025$) before the hazard were closer to the bus hazard compared to at 2 ($M = -0.292$) or 3 seconds ($M = -0.243$) before the bus hazard.

Figure 24

Mean lane offset (in meters) for bus-behavioral scenario.

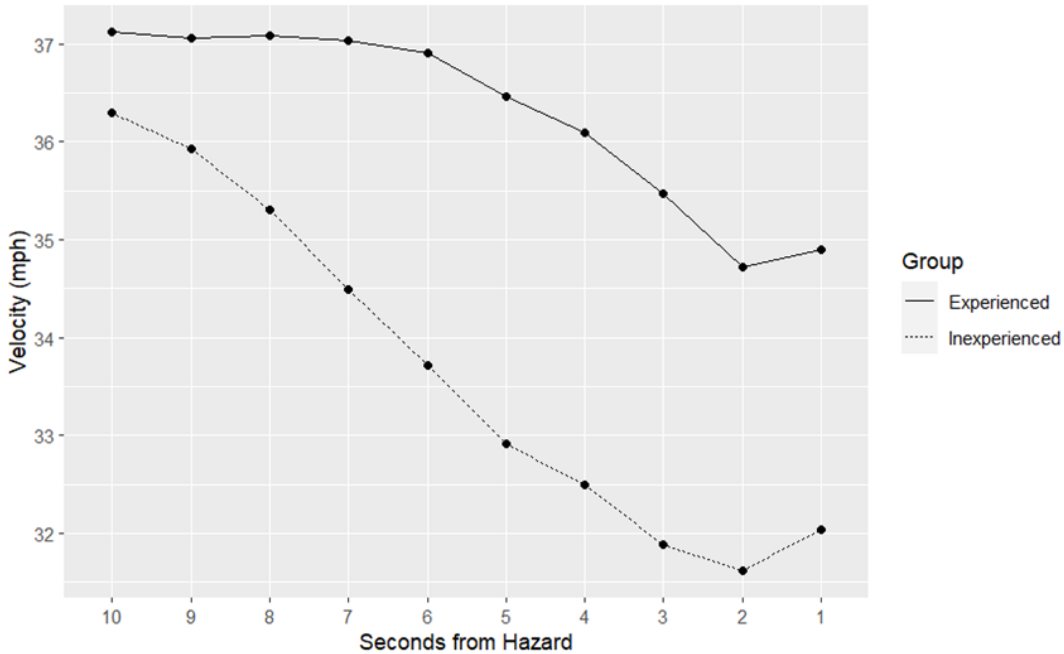


Note. In this scenario, the more negative the value, the further away the vehicle was from the bus hazard.

Truck. There was a decisive main effect of group on velocity, $F(1, 38) = 2.18$, $B_{10} = 297.62$, $\eta^2_G = 0.041$ (Figure 25). Experienced drivers drove decisively faster ($M = 36.29$) than inexperienced drivers ($M = 33.67$) in the 10 seconds before the construction hazard, $t(398) = 4.02$, $B_{10} = 243.43$.

Figure 25

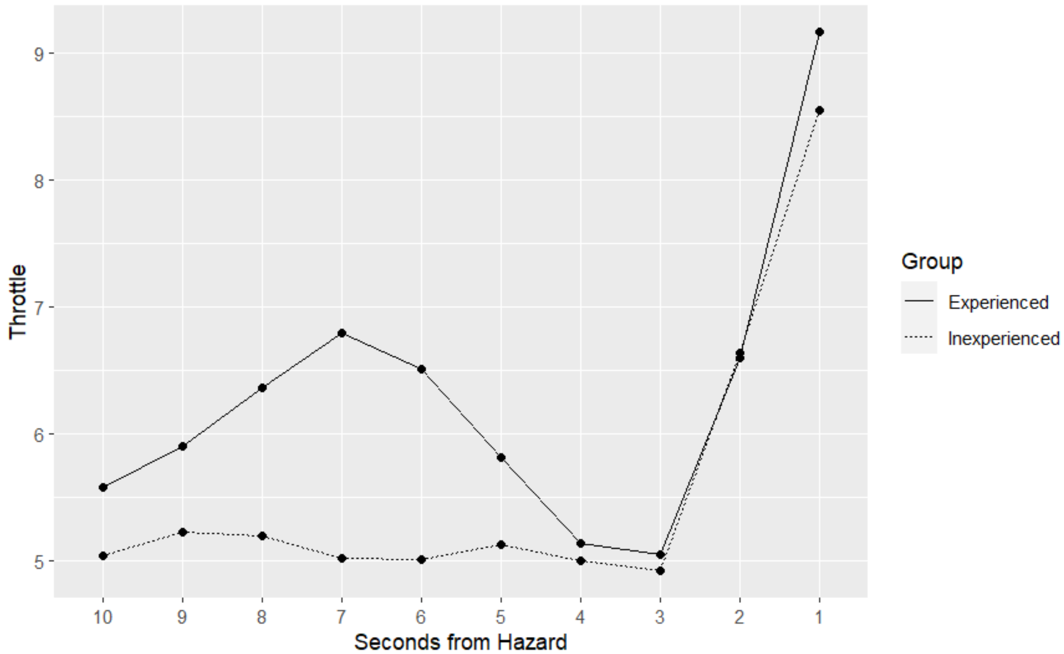
Mean velocity (mph) for truck-behavioral scenario.



There was a decisive main effect of time on throttle pedal position, $F(2.35, 89.32) = 6.50$, $B_{10} = 1{,}754.39$, $\eta^2_G = 0.097$ (Figure 26). At one second ($M = 8.86$) before the hazard, participants depressed the throttle pedal more than at 3 ($M = 4.99$), 4 ($M = 5.07$), 5 ($M = 5.47$), 6 ($M = 5.76$), 7 ($M = 5.91$), 8 ($M = 5.78$), 9 ($M = 5.57$) or 10 seconds ($M = 5.31$) before the hazard.

Figure 26

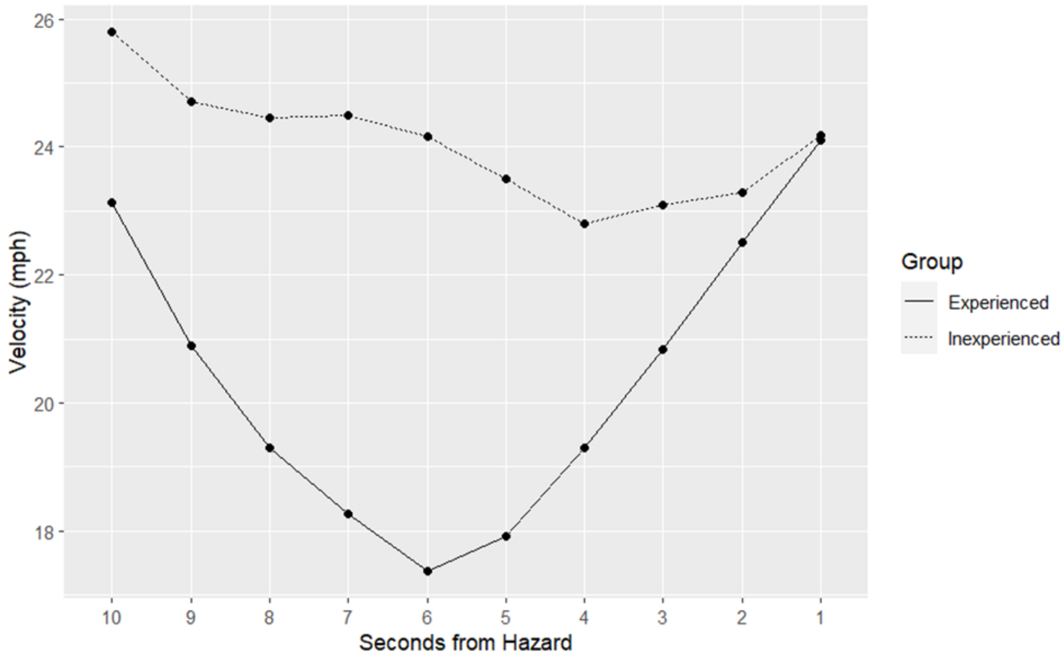
Mean throttle pedal position (degrees) for truck-behavioral scenario.



Construction. There was a decisive main effect of group on velocity, $F(1, 38) = 2.70$, $B_{10} = 452.49$, $\eta^2_G = 0.063$ (Figure 27). Experienced drivers drove decisively slower ($M = 20.26$) than inexperienced drivers ($M = 24.05$) in the 10 seconds before the construction hazard, $t(398) = -4.14$, $B_{10} = 376.28$.

Figure 27

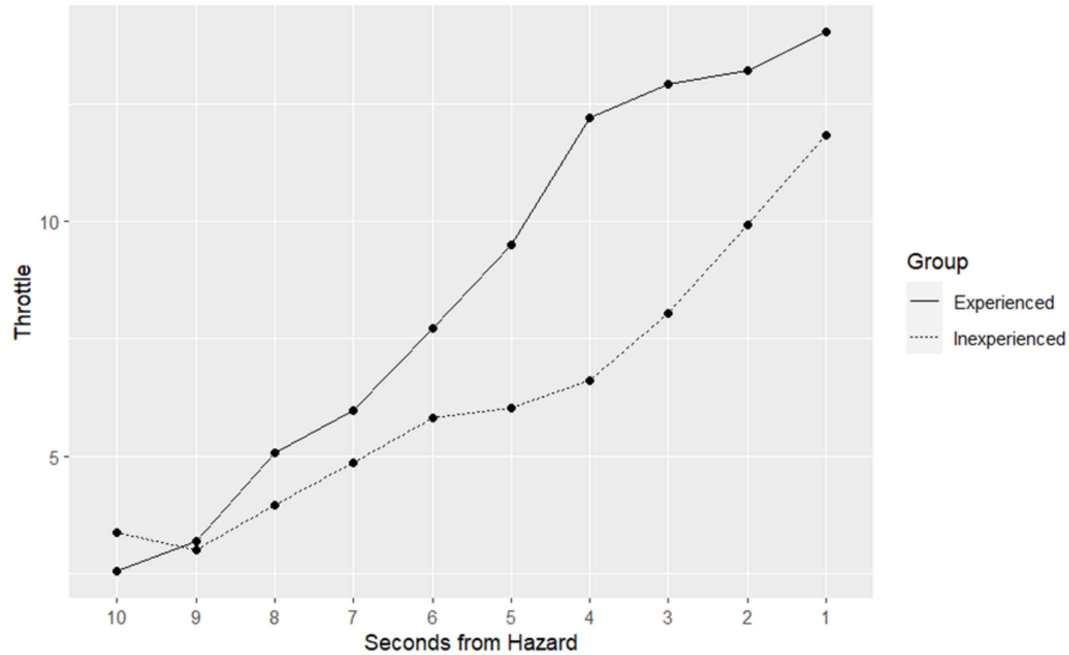
Mean velocity (mph) for construction-behavioral scenario.



There was a decisive main effect of group on throttle pedal position, $F(1, 38) = 7.53$, $B_{10} = 2500$, $\eta^2_G = 0 .053$ (Figure 28). Experienced drivers depressed the throttle pedal decisively more ($M = 8.64$) than inexperienced drivers ($M = 6.35$), $t(398) = 3.81$, $B_{10} = 112.74$. There was also a decisive main effect of time on throttle pedal position, $F(2.13\ 81.02) = 25.25$, $B_{10} = 9.08 \times 10^{24}$, $\eta^2_G = 0.324$. Participants depressed the accelerator less when approaching the hazard, 10 ($M = 2.96$), 9 ($M = 3.09$), 8 ($M = 4.49$), 7 ($M = 5.40$), 6 ($M = 6.76$), 5 seconds ($M = 7.76$) compared to 2 ($M = 11.59$) and 1 ($M =12.94$) second before the hazard.

Figure 28

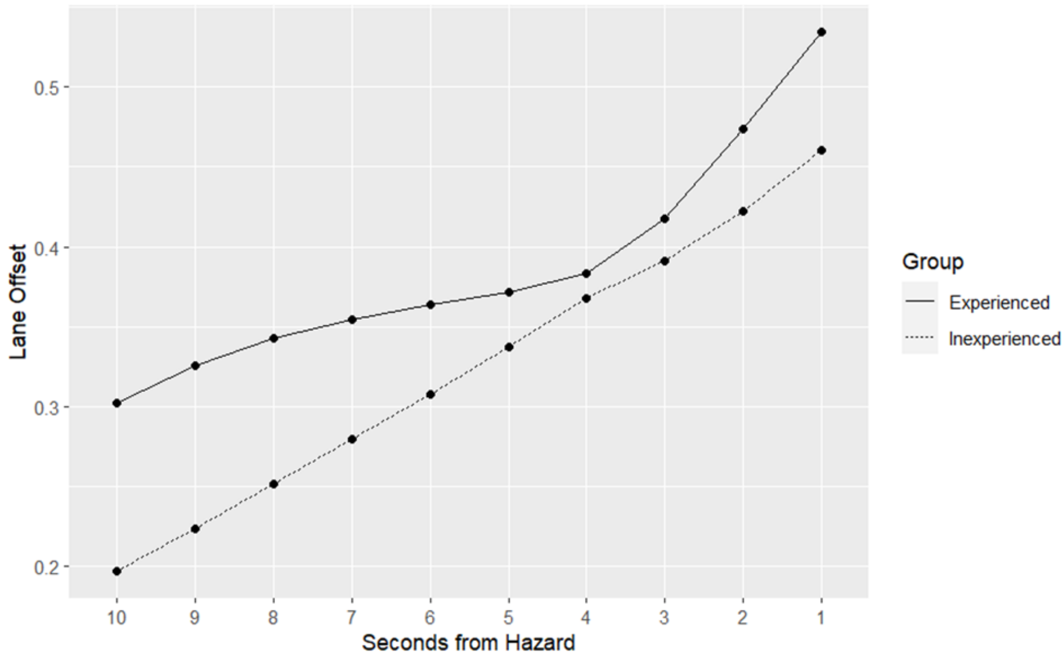
Mean throttle pedal position (degrees) for construction-behavioral scenario.



There was a strong main effect of group on lane offset position, $F(1, 38) = 1.45$, $B_{10} = 23.80$, $\eta^2_G = 0.028$ (Figure 29). Experienced drivers drove more to the right ($M = 0.39$), further from the construction hazard, compared to inexperienced drivers ($M = 0.32$), $t(398) = 3.15$, $B_{10} = 12.80$. There was also a decisive main effect of second on lane offset position, $F(1.76, 66.7) = 25.35$, $B_{10} = 2.99 \times 10^6$, $\eta^2_G = 0.137$. Participants drove more to the right (further from the construction hazard) earlier in the drive at 10 ($M = 0.250$), 9 ($M = 0.275$), 8 ($M = 0.297$),7 ($M = 0.317$), 6 ($M = 0.336$), and 5 ($M = 0.354$) seconds compared to 1 second before passing the hazard ($M = 0.497$).

Figure 29

Mean lane offset (in meters) for construction-behavioral scenario.

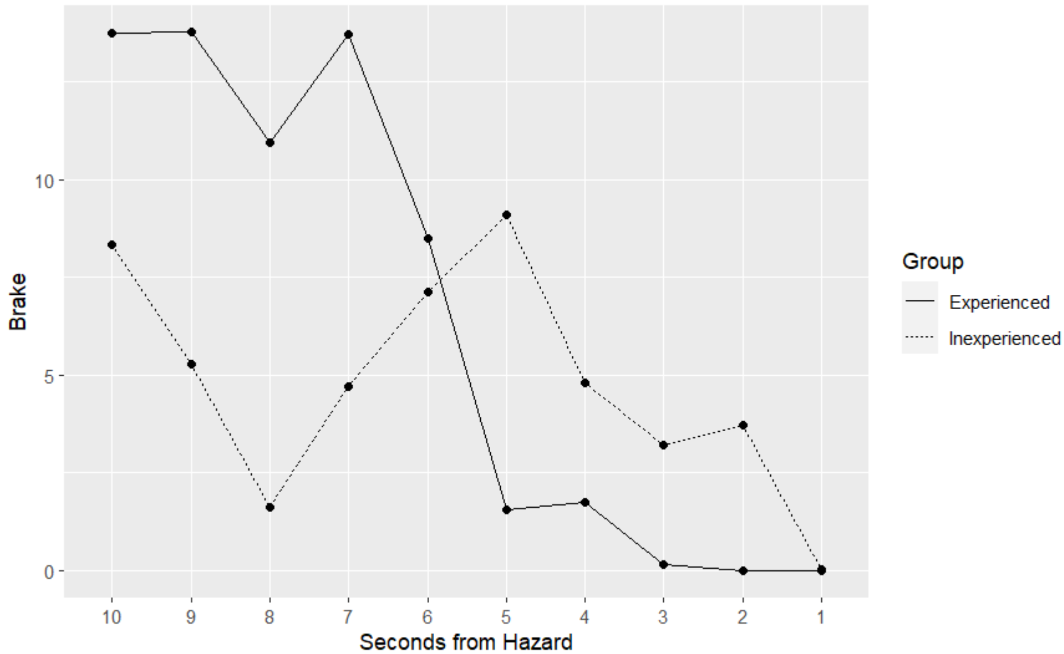


Note. In this scenario, the more positive the value, the further away the vehicle was from the construction hazard.

There was a substantial main effect of second on brake force, $F(3.76, 143.03) = 3.11$, $B_{10} = 8.27$, $\eta^2_G = 0.019$, with participants applying the brake more at 10 seconds before passing the hazard ($M = 11.04$) compared to 1 second before passing the hazard ($M = 0.02$) (Figure 30).

Figure 30

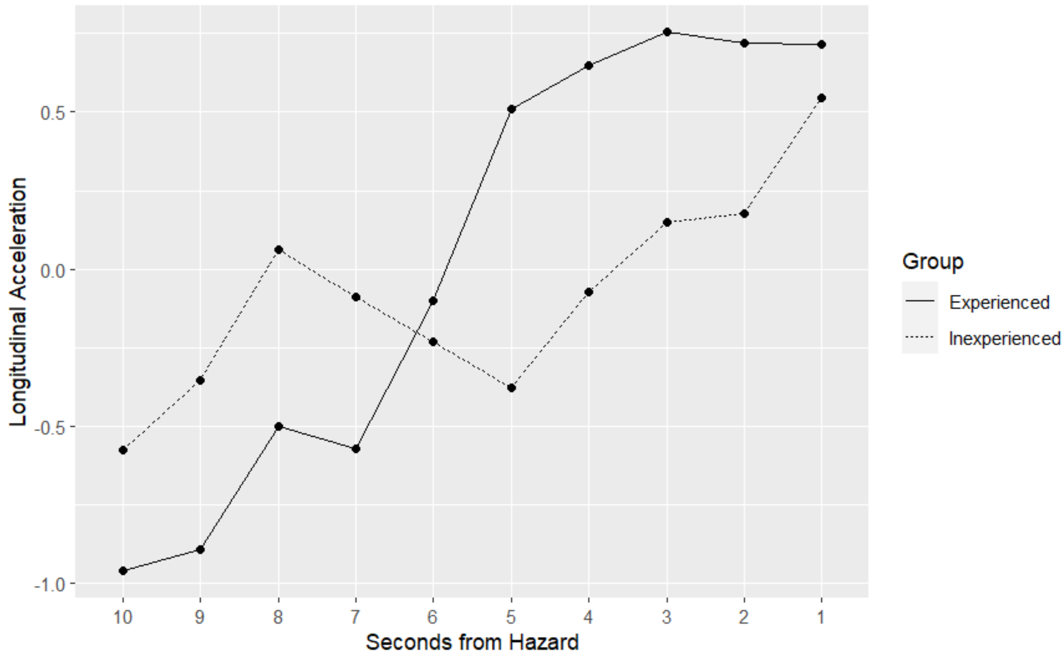
Mean brake force (N) for construction-behavioral scenario.



There was a decisive main effect on time on longitudinal acceleration, $F(3.43, 130.25) = 5.70$, $B_{10} = 1.88 \times 10^4$, $\eta^2_G = 0.112$, with participants accelerating further from the hazard 10 ($M = -0.76$) and 9 seconds ($M = -0.62$) before passing the hazard, compared to 1 ($M = 0.63$) and 2 seconds ($M = 0.44$) before the hazard (Figure 31).

Figure 31

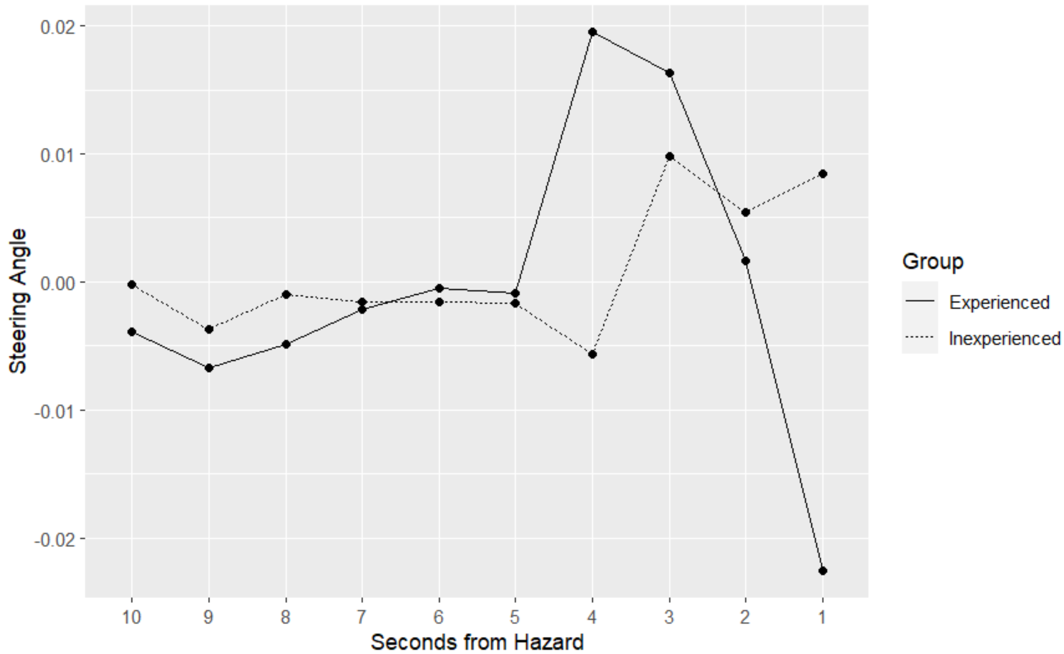
Mean longitudinal acceleration (m/s^2) for construction-behavioral scenario.



There was a substantial interaction between time and group such that experienced drivers steered more to the right than inexperienced drivers at 4 seconds before the hazard (*M* = 0.019 vs. *M* = -0.006), but experienced drivers steered more to the left at 1 second before the hazard compared to inexperienced drivers (*M* = -0.022 vs. *M* = 0.008), $F(5.02, 190.68) = 2.69$, B_{10} = 8.67 , $\eta^2_G = 0.063$ (Figure 32). This can be interpreted as experienced drivers steered away from the hazard about 4 seconds before approaching, but corrected just before the hazard when they interpreted that hazard did not pose a threat.

Figure 32

Mean steering angle for construction-behavioral scenario.



Note. More positive angle indicates the driver steering further away from the construction hazard.

Midblock crosswalk. There was a substantial main effect of group on throttle pedal position, $F(1, 38)$ =3.45, B_{10} = 4.12, η^2_G = 0.019 (Figure 34). Experienced drivers depressed the throttle pedal more (M = 5.18) than inexperienced drivers (M = 4.07). There was also a decisive main effect of second on throttle pedal position, $F(2.14, 81.16)$ = 17.46, B_{10} = 5.32 x 10^{18}, η^2_G = 0.265. Participants depressed the accelerator more at 1 second before the hazard (M = 9.92) versus 3 (M = 5.69), 4 (M = 5.00), 5 (M = 4.22), 6 (M = 3.27), 7 (M = 2.74), 8 (M = 2.60), 9 (M = 2.51), and 10 (M = 2.64) seconds before the hazard. Participants also depressed the accelerator more at 2 seconds before the hazard (*M* = 7.62) compared to at 5, 6, 7, 8, 9, and 10 seconds before the hazard.

Figure 33

Mean velocity (mph) for midblock crosswalk -behavioral scenario.

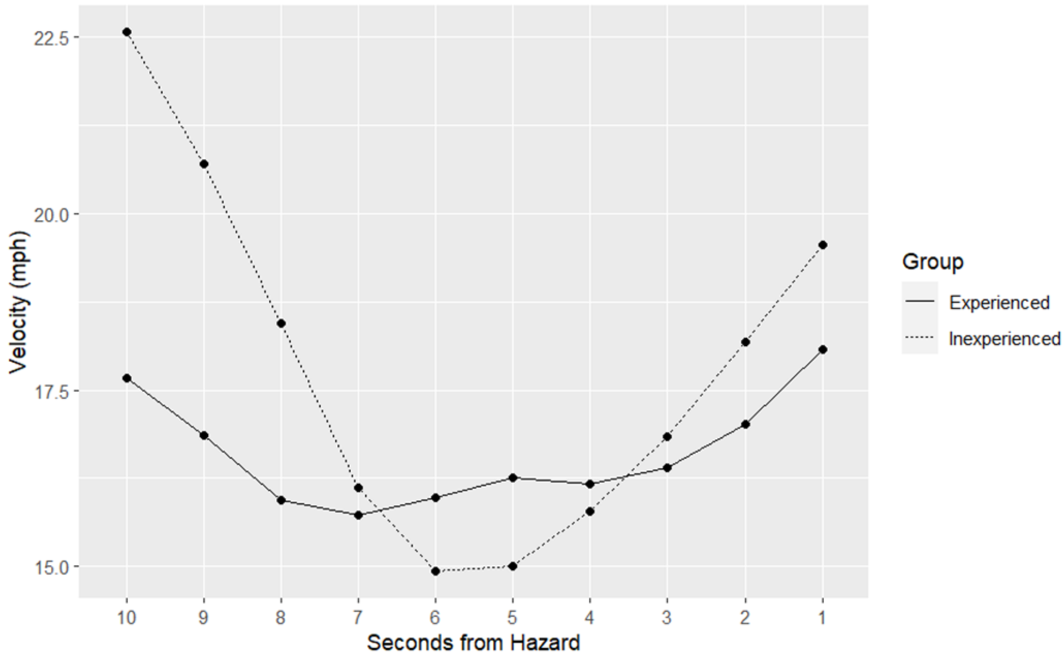
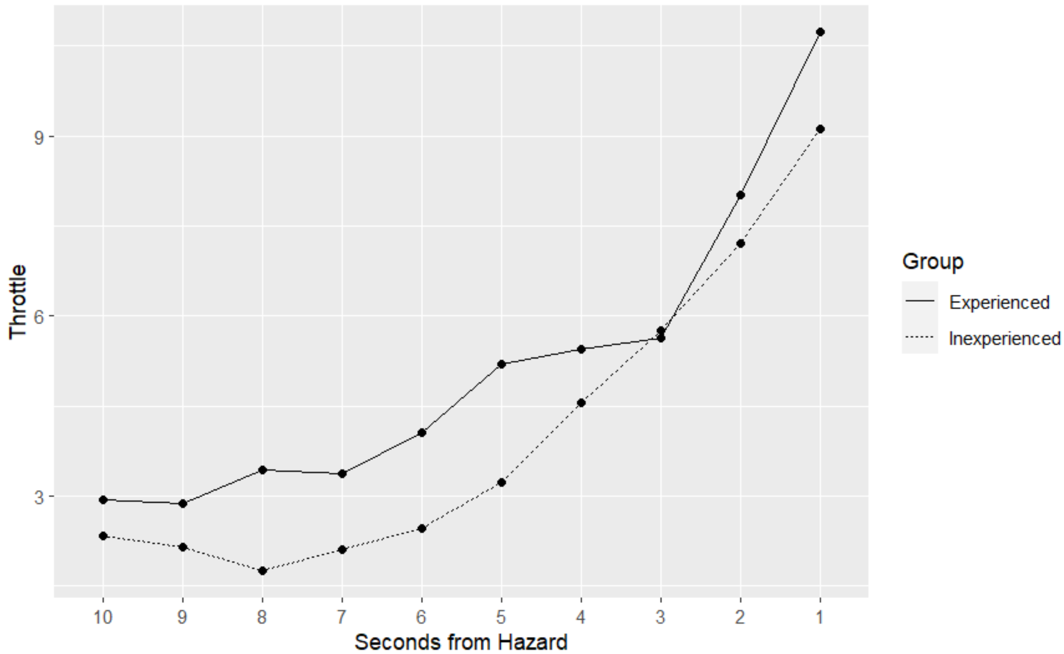


Figure 34

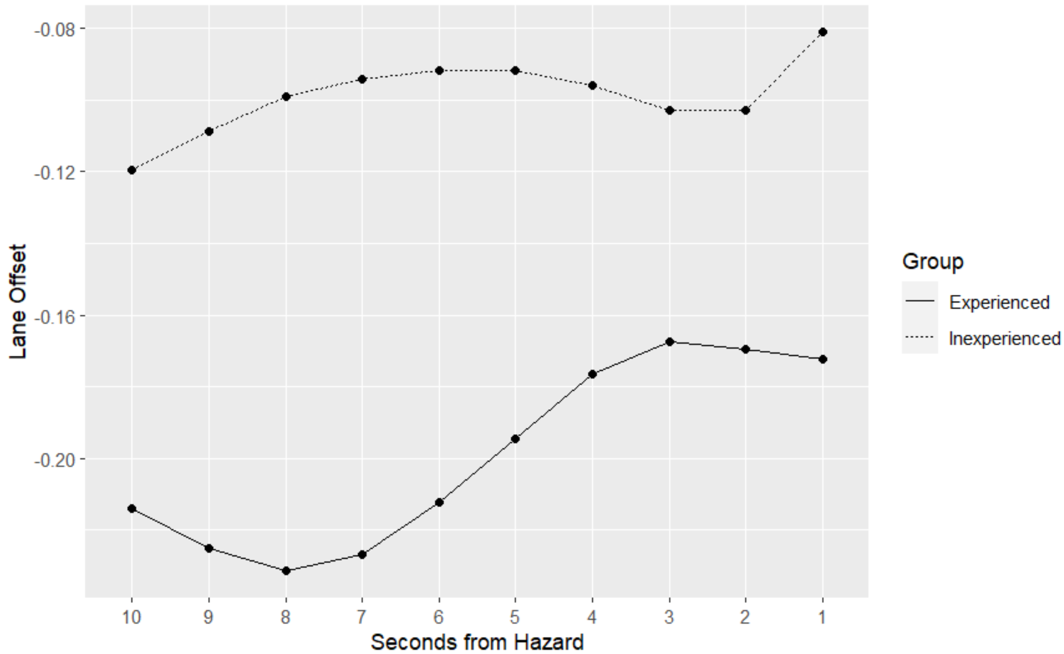
Mean throttle pedal position (degrees) for midblock crosswalk-behavioral scenario.



There was a decisive main effect of group on lane offset position, $F(1, 38) = 2.51$, $B_{10} =$ 4,424.78, $\eta^2_G = 0.053$ (Figure 35). Experienced drivers drove decisively more to the left (M = -0.20), further from the midblock-crosswalk hazard, compared to inexperienced drivers (M = -0.10), $t(398) = -4.72$, $B_{10} = 4094.51$.

Figure 35

Mean lane offset (in meters) for midblock crosswalk-behavioral scenario.

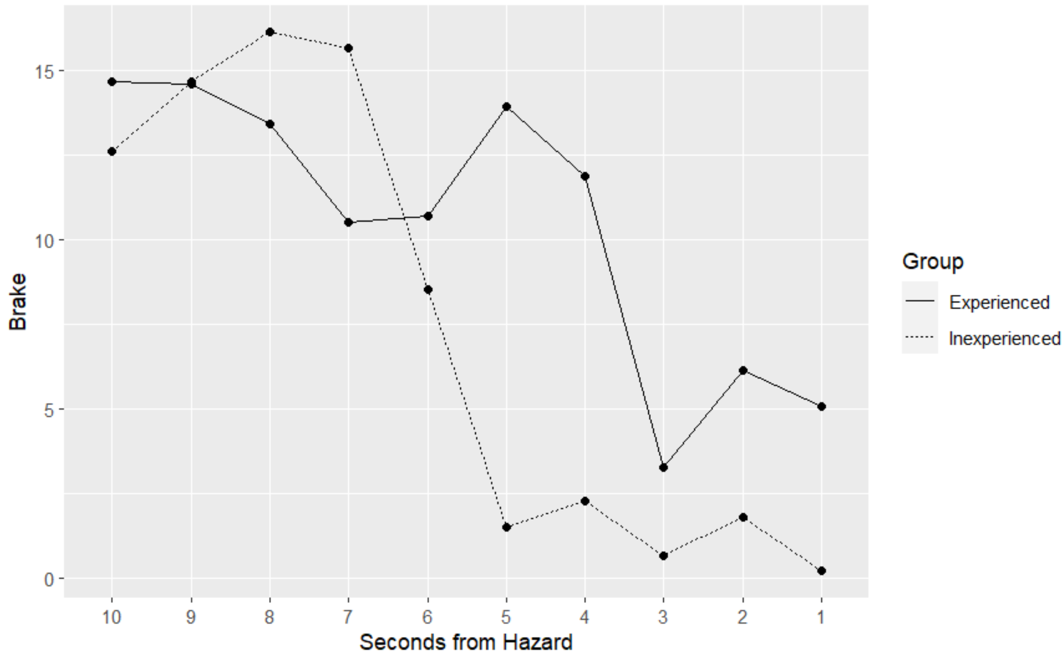


Note. More negative values denote areas of the lane further from the crosswalk hazard.

There was a strong main effect of second on brake force, $F(3.41, 129.61) = 3.88$, $B_{10} = 28.54$, $\eta^2_G = 0.074$ (Figure 36). Participants applied less brake force 3 seconds ($M = 1.98$) versus 8 seconds ($M = 14.77$) before the hazard.

Figure 36

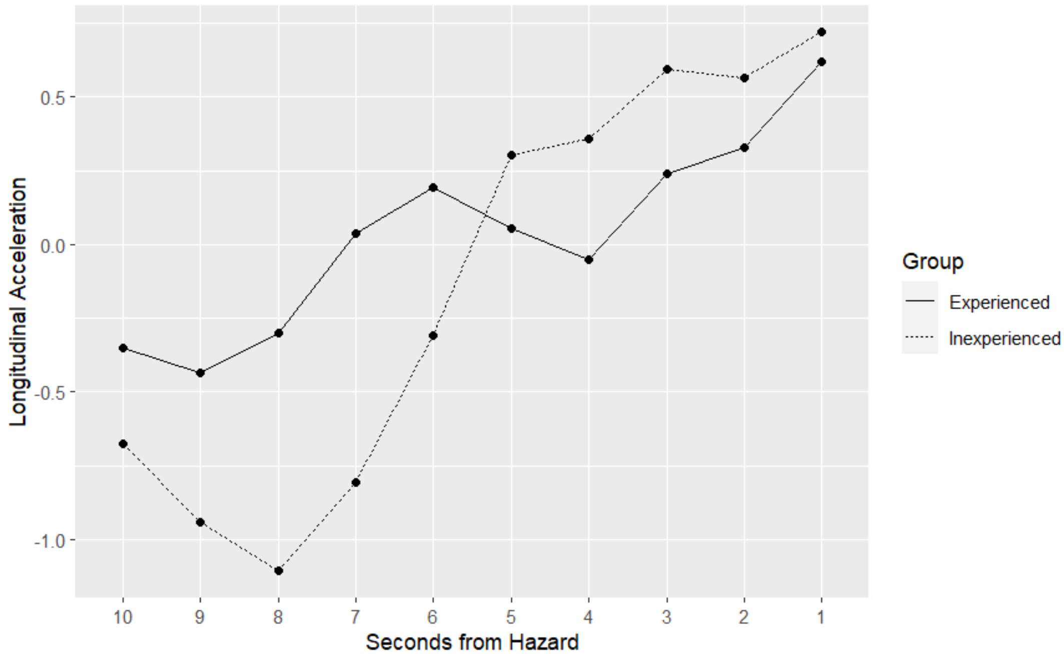
Mean brake force (N) for midblock crosswalk-behavioral scenario.



There was a decisive main effect of seconds on longitudinal acceleration, $F(3.18, 120.98) = 6.02$, $B_{10} = 5.37 \times 10^4$, $\eta^2_G = 0.117$ (Figure 37). Participants accelerated at 1 second ($M = 0.67$) before the hazard, whereas they deaccelerated when approaching the hazard at versus 7 ($M = -0.39$), 8 ($M = -0.70$), 9 ($M = -0.68$) and 10 seconds ($M = -0.51$) prior to the hazard.

Figure 37

Mean longitudinal acceleration (m/s^2) for midblock crosswalk-behavioral scenario.



Crash Avoidance

In the behavioral CA scenario, 70% of both experienced and inexperienced drivers avoided colliding with the vehicle. In the environmental CA scenario, 30% of experienced and 10% of inexperienced drivers avoided colliding with the vehicle. Due to the small number of observations for each condition, a Fisher's exact test was conducted, which showed no evidence there were differences in likelihood to successfully mitigate the hazard between the experienced and inexperienced groups in either the behavioral (p = 1.0, B_{10} = 1/1.16) or environmental (p = .582, B_{10} = 1.28) HM condition.

In addition, two binomial logistic regressions were conducted to examine the possible relationship between an individual's average tactical HA score and operational HA score on whether or not they successfully avoided the hazard (the behavioral and environmental CA groups were analyzed separately). For the behavioral CA group, neither average tactical nor operational HA score predicted successful mitigation of the hazard, slopes $\leq |1.5|$. However, in the environmental CA group, average operational HA was positively related to likelihood of avoiding the hazard, slope = 6.1, 90% BCI = [0.3, 15.0]. Tactical HA was not related to likelihood of avoiding the hazard, slope = 0.9, 90% BCI = [-3.8, 6.7].

CHAPTER IX

DISCUSSION

The purpose of this study was to investigate the novel concept of operational hazard anticipation (Yamani et al., 2021) and its potential relationship to both tactical hazard anticipation (fixating on a hazard or potential hazard), hazard mitigation behaviors (taking action to avoid a hazard when it appears on the road) and collision avoidance. Using a high-fidelity driving simulator, both inexperienced (ages 18-21) and experienced (ages 30-64) participants navigated a series of scenarios, each with a hazard present on the road. At the end of the study, participants drove one scenario where the hazard *did* materialize on the road. I hypothesized that experienced drivers would exhibit better operational HA than inexperienced drivers and that both groups would engage in operational HA in the behavioral hazard scenarios more than the environmental hazard scenarios. I also hypothesized that tactical HA would show an interaction such that experienced drivers would have higher levels of tactical HA for both environmental and behavioral hazard scenarios compared to inexperienced drivers but that both groups would exhibit more tactical HA in the behavioral hazard scenarios compared to the environmental hazard scenarios.

The data in the present study suggest that experienced drivers were more likely to exhibit operational HA behaviors (i.e., moving their foot in a way that suggests preparing for an action) compared to younger drivers. This effect held in both the behavioral scenarios (where the hazard was visible to the driver) and the environmental scenarios (where the hazard was latent/hidden). In addition, there was a main effect of hazard type where drivers were more likely to exhibit operational HA in behavioral hazard scenarios compared to environmental hazard scenarios. These two effects support my hypotheses on the expected patterns of operational HA.

The evidence did not support my hypotheses on tactical HA performance. Although the drivers tactically anticipated more behavioral than environmental hazards, this effect of scenario type did not vary between inexperienced and experienced drivers. Furthermore, experienced drivers had numerically higher tactical HA scores than inexperienced drivers in the environmental condition, but this effect was not substantial. This data pattern is not inconsistent with the previous studies because the literature repeatedly demonstrate that drivers are more likely to fixate to a visible hazard than an occluded hazard (Yamani et al., 2016). Consider latent hazard scenarios used in Yamani and colleagues (2016) where drivers navigated two sets of scenarios: One with hazards occluded to the drivers (hazard anticipation scenarios) and the other with hazards that are readily visible to the drivers (hazard mitigation scenarios). In both types of scenarios, the hazard did not materialize. The researchers observed that the percentage points of scenarios where the drivers correctly fixated to the target zones were higher for hazard mitigation scenarios than hazard anticipation scenarios. Translating the scenario types used in Yamani et al. (2016) to the current study, the environmental hazard scenarios correspond to hazard anticipation scenarios while the behavioral hazard scenarios correspond to hazard mitigation scenarios. It is possible that, because the drivers fixated to the target zones so well due to the saliency of the behavioral hazard, their ceiling performance washed away the main effect of group as well as the interaction. This context suggests that it was the structure of the study design itself, as opposed to other considerations such as too small of a sample size (see Appendix D for Bayesian design analysis), which explains why the expected interaction and main effect of group were not present in tactical HA.

In addition, the data partially support my hypothesis that operational HA performance would be related to an individual's likelihood of successfully mitigating a hazard that appeared on the road. A Bayesian logistic regression suggests that there was a relationship between operational HA performance and mitigating the hazard, but only for people who went through the environmental version of the CA scenario. Neither tactical nor operational HA performance was predictive of successfully mitigating the behavioral CA scenario, possibly due to the high proportion of participants who were able to avoid the hazard and the fact that inexperienced and experienced participants avoiding the hazard at the same rate.

Although some of the findings were expected, the present results open up additional questions, discussions, and avenues for future research and applications.

Operational and Tactical Hazard Anticipation

Given that this is the first study to examine the possible concept of operational hazard anticipation and relationship between operational hazard anticipation and hazard avoidance actions, there are several areas of discussion on how to define, study, and use the concept in hazard avoidance research. The first, most basic question this study sought to answer was if operational HA even exists as a pattern of driver behavior. Although it had been proposed as a distinct level of latent HA (Yamani et al., 2021), there had been no validated measures of operational HA or even qualitative examination of its existence or prevalence when driving. This study suggests that both a) drivers do exhibit types of behaviors that stem from operational HA and b) experienced drivers are more likely to exhibit operational HA compared to inexperienced drivers. Together, these findings support the idea that operational HA is a behavioral pattern that is developed as drivers obtains more experience on the road, similar to tactical HA (Pradhan et al., 2005) and hazard mitigation (Muttart et al., 2013). The exact mechanism of how this behavior develops is still uncertain. With increased levels of experience, drivers may learn to recognize hazards on the road, even when they are not salient (like how it is hypothesized drivers develop tactical HA; Unverricht et al., 2018). However, in both groups, operational HA was shown more frequently in behavioral hazard scenarios compared to environmental hazard scenarios. The behavioral hazards were not only more salient that the environmental hazards since the hazard was overt, but because it was moving, the behavioral hazards were interpreted as being more likely to develop in a way that needed to be mitigated compared to the environmental hazards. In this way, operational HA could be a response to seeing a hazard that may need to be mitigated.

However, operational HA goes beyond mere recognition of a hazard; the lack of correlation between an individual's average operational HA score and tactical HA score suggests that the two measures are capturing different processes or individual strategies of hazard avoidance. Shifting one's foot position when approaching a hazard could indicate that the driver is preparing to mitigate a hazard should it become a threat to the driver, as proposed by Yamani and colleagues (2021). In addition to this definition, operational HA may offer drivers a way to monitor how a situation on the road is developing and collect more information from the environment before deciding to make an evasive maneuver or not. Experienced drivers understand that not every hazard and potential hazard on the road requires sudden braking or swerving into the adjoining lane (indeed such mitigation actions may be more dangerous than the hazard itself) and shifting foot position may give drivers the chance to wait until the last second before making such a decision. In contrast, inexperienced drivers may not decide to continuously monitor a potentially hazardous situation on the roadway, either because they do not comprehend it as hazardous or because they assume every threat requires an immediate response.

In this way, the anticipatory actions shown via operational HA can be conceptualized as the culmination of a driver's evaluation of the roadway, but short of actual hazard mitigation. Although an information-processing-based model of situation awareness (SA) (Endsley, 1995) cannot account for all complex subprocesses that incorporate elements such as hazard and precursor cues in the driving environment (Pradhan & Crundall, 2017), it provides a useful framework for why and when drivers engage in operational HA and its relationship to other forms of HA (Yamani et al., 2021). When approaching an area of a potential hazard, a driver must first perceive the hazard (Level 1 SA). Broadly scanning the environment and using the road geometry can provide drivers clues as to where hazards may occur, representing modal HA as defined by Yamani and colleagues (2021). Strategic HA, where a driver uses hazard precursors (such as a "crosswalk ahead" sign) to anticipate the upcoming presence of hazards and tactical HA signify comprehension of the placement of the hazard and its potential risk (Level 2 SA). In turn, operational HA could reflect a driver's specific prediction (or projection) of how the roadway environment and hazards are likely to evolve (Level 3 SA). For example, if a driver predicts a pedestrian is likely to walk in front of them, they may engage in operational HA behaviors specific to the context. Crucially, Level 3 SA refers to one's cognitive processes, not actions, suggesting that anticipatory behaviors reflected in operational HA, but not actual hazard mitigation, fits with this SA model.

Second, this study aimed to investigate potential measures of operational HA. Two measures were initially proposed: coding if a driver was hovering their foot over the accelerator or brake as an indicator of readiness to brake and coding if a driver shifted their hand position on the steering wheel when approaching the hazard as an indicator of readiness to swerve. Unfortunately, participants were only observed shifting their grip on the steering wheel in 4 of the possible 359 experimental trials. This was slightly surprising due to a previous study showing that drivers in high speed (100 km/h) zones were more likely to have their hands on the top portion of the steering wheel than in lower speed zones (50 km/h) (Walton & Thomas, 2005). However, given the lack of steering wheel grip movement observed in the present study, grip position may be more of an indicator of need for vehicle control at higher speeds than a response to the comprehension of risk or hazards on the road ahead. At least in the present context, hand position was ruled out as a useful measure of operational HA. As such, only foot position was used as a potential indicator or operational HA. The fact that there were group level differences in foot movement with experienced drivers exhibiting them more than inexperienced drivers suggest that these driving behaviors patterns are internally valid and may be linked to increased likelihood of collision avoidance. Given that older, more experienced drivers have lower crash risk compared to younger, less experienced drivers (Tefft, 2017), it is possible that operational HA may be related to safety outcomes, although definitive conclusions are premature at this point of early exploration and require a wide-scale on-road study that directly relates operational HA skills in young drivers and their crash rates.

Third, there appears to be a wide range of deployment of operational HA responses, implying that operational HA may not be a skill everyone uses. Averaged across the eight scenarios, participants' operational HA scores ranged from 0 to 87.5%. Even amongst experienced drivers, three participants did not demonstrate any operational HA behavior in any of the eight scenarios. As such, based on these data, operational HA appears to be a skill that not *all* drivers develop as they gain driving experience. Relating to a point above, operational HA may be susceptible to larger individual differences than tactical HA. Operational HA may function as an individual behavioral strategy some drivers choose to deploy if their assessment of a road environment warrants it. The exact demographic, personality, or driving history factors that lead to a driver to engage in operational HA is unclear; all demographic factors (such as gender) and driving factors (such as history of violations) were not related to either operational or tactical HA. However, because not all drivers demonstrate operational HA behaviors, training has the potential to encourage drivers to engage in preparatory actions more often when approaching and monitoring hazardous situations. Such training could have important safety consequences; exploratory analyses on the relationship between operational and tactical HA and CA suggest that drivers who deploy operational HA behaviors ahead of a potential hazard were more likely to avoid the hazard in the environmental CA scenario, independent of tactical HA, implying these behaviors could help drivers effectively mitigate dangers on the road.

Collision Avoidance Performance

Due to practical research limitations (after exposure to a single CA scenario, participants can become overly cautious when driving through the simulated environment, expecting a more frequent onset of hazards), collision avoidance and hazard mitigation are less studied than hazard anticipation. The present study offered an opportunity to examine not only operational and tactical hazard anticipation, but the potential relationship of these concepts on collision avoidance. Using Fisher's exact test, there was no evidence to suggest that the proportion of experienced drivers who successfully avoided the hazard was different than the proportion of inexperienced drivers who successfully avoided the hazard. This finding was true in both the behavioral and environmental CA scenario. However, in the environmental CA scenario, 3 out of 10 experienced participants were able to mitigate the hazard whereas only 1 out of 10 inexperienced drivers was able to mitigate the hazard. Therefore, it is possible that due to small cell sizes, statistical tests were not able to detect proportion differences. Another challenge of designing collision avoidance scenarios is finding a happy medium between hazards that are too difficult to avoid and hazards that are too easy. Using both behavioral and environmental CA scenarios, we ensured a range of responses.

Unlike in Muttart et al. (2013), we did not find evidence to suggest that a participant's average tactical hazard anticipation score was related to whether they were able to successfully avoid the hazard or not. This applied to both the easier behavioral CA scenario and the more difficult environmental CA scenario. Although somewhat surprising, the fact that there was evidence linking operational HA and collision avoidance suggests that preparatory behaviors are more likely to lead to a quick and suitable response to an imminent hazard compared to just fixating on the placement of hazards or likely hazards.

Hazard Mitigation Driving Behavior Measures

Driving behavior was examined to investigate possible hazard mitigation patterns between hazard scenario types and experience groups. Group differences in velocity and lane offset were found in five out of eight scenarios. In four out of the five scenarios where there was a main effect group on velocity, the experienced group drove slower than the inexperienced group, including in two environmental scenarios (construction and midblock crosswalk). Although this finding is consistent with the observation that experienced participants shifted their foot position to hover over either the accelerator or brake pedal (if one releases the accelerator, the car will inevitably slow down), there was no main effect of second or interaction between second and group on velocity, suggesting that experienced drivers may have been driving slower overall as opposed to in response to an upcoming hazard. Throttle pedal position may be a closer behavioral analogue to the operational HA measure used in the current study. However, in the two scenarios where there were group differences in throttle position, the experienced group depressed the throttle pedal *more* than the inexperienced group, suggesting that driving behavior metrics may not capture all aspects of preparatory actions operational HA seeks to measure.

Theoretical and Practical Implications

Although this current research project investigates a new and novel concept, there are several theoretical and practical implications that we can draw from the results. First, age differences in tactical HA performance have been well-documented with older, more experienced drivers being more likely to fixate on potential (latent) hazards compared to younger, less experienced drivers (Pradhan et al., 2005). Although this finding was not replicated here (as noted above, most likely due to the inclusion of behavioral hazard types in the model), present data suggest that operational HA may also be able to distinguish experienced from inexperienced drivers, implying that it may be a skill that is developed through experience and exposure to the driving environment.

In addition, although detailed analysis on *when* participants deployed operational HA in relation to the upcoming hazard was not conducted, anecdotally, drivers deployed these behaviors at a range of points when approaching the hazard (video was coded for operational HA behaviors approximately 7 seconds prior to the hazard). Unlike Pradhan and Crundall's (2017) framework which categorizes different hazard avoidance behaviors into spatial zones in relation to the hazard, Barragan and colleagues' (2021) dynamic hazard perception-response framework conceptualizes hazard avoidance as stages in which the driver continuously detects, comprehends, responds, and monitors, and makes continual adjustments to their behavior based on new information. Considering operational HA was not deployed at a specific spatial proximity to the hazard, the data fit more closely with the hazard perception-response framework, suggesting that developing static, spatial zones for hazard avoidance is too narrow to account for the continual and dynamic nature of hazard avoidance.

Practically, operational HA opens up a new avenue for training young, inexperienced drivers to obtain skills needed to reduce the likelihood of crashes. Evaluations of previous trainings for HM have been inconclusive, and it is unclear if training on mitigation behaviors or hazard anticipation itself account for improvements in HM and CA scenarios (Muttart et al., 2019; Yamani et al., 2016). However, training inexperienced drivers about operational HA may offer drivers a way to start mitigating a hazard (while continuing to monitor it) without making sudden or dangerous action. In effect, operational HA could provide inexperienced drivers a step between anticipating a hazard and responding to it.

Limitations

There are several constraints to the current study that limit its application. Given the small cell size for CA scenario variations (only 10 experienced and 10 inexperienced drivers went through each of the behavioral and environmental CA scenario), there may have been insufficient power to detect the relationship between CA performance and tactical HA that was present in a previous study (Muttart et al., 2013). Although the data suggest that there was a relationship between operational HA performance and avoiding a collision in the more difficult environmental CA scenario, only four participants in total were able to avoid the environmental hazard, and definitive conclusions between the two concepts would be premature.

Given that this study was conducted in a driving simulator, it is possible that the results, specifically findings to suggest operational HA may be a construct separate from tactical HA, would not translate to the road. An on-road study will allow us to examine if drivers regularly deploy operational HA tactics and if this deployment is related to driving experience as it was in the present study. Due to the fact they were being observed in a lab, some participants may have been extra cautious when driving, either because they expected something novel to occur on the roadway or because they wanted to manage appearances of being a safe driver. This may have encouraged them to engage in preparatory actions more frequently than they otherwise would in a real-world driving environment. Alternatively, participants may have felt that because the risk of physical harm was absent if they ended up colliding with a road object or other vehicle in the driving simulator, they did not need to engage in preparatory actions during the study to the same level they would if they were driving on the road. On-road study to measure and analyze operational HA behaviors would increase external validity of this study.

Future Research

As noted above, individual differences such as gender, number of days per week driven, and history of violations or crashes in the past three years were not related to any of the studied measures. However, for operational HA specifically, a wide range of scores were exhibited, even for the experienced group. Investigating the relationship between other participant factors, such as propensity for risk taking, sensation seeking, and aggression, could shed light on who is most likely to engage in operational HA tactics and in turn receive maximal benefit of a training program that focuses on operational HA. For example, research has demonstrated young drivers categorized as “careful” (based on scoring of both driving aggressiveness and sensation seeking questionnaires and reported history of driving violations) benefitted from a hazard anticipation and attention maintenance training whereas young drivers categorized as “careless” did not (Zhang et al., 2018). As such, future research should not only explore how these factors relate to operational HA and hazard mitigation but develop ways to encourage the most training-resistant (and yet, at risk) populations to adopt safer driving behaviors.

Considering movement of hand position was rarely observed in the recorded trials, only foot movement was recorded and reported as a measure of operational HA. Future research could examine other potential measures of operational HA and investigate if these hypothesized measures are correlated with drivers' foot movements. For example, even though change of hand position proved to be an ineffective measure, steering wheel grip force (previously examined as an indicator of stress; Sahar et al., 2021) may be related to a driver's readiness to swerve to mitigate a hazard.

CHAPTER X

CONCLUSIONS

This study sought to investigate the novel concept of operational HA and its relationship to both tactical HA and collision avoidance performance. Experienced drivers demonstrated more operational HA behaviors compared to inexperienced drivers, supporting operational HA as a skill set that is related to experience on the road. Additionally, when drivers were exposed to a surprise CA event, drivers who had higher operational HA scores were more likely to avoid the hazard, suggesting that these behaviors are linked to collision avoidance. These data can inform the broader theory of hazard avoidance processes and support a dynamic framework of hazard avoidance as opposed to a static, spatially based framework of hazard avoidance. Future research should focus on developing additional measurements of operational HA such as steering wheel grip and investigating the potential for operational HA to be incorporated into training programs designed to improve safe driving behaviors in young drivers.

REFERENCES

Barragan, D., Peterson, M. S., & Lee, Y.-C. (2021). Hazard Perception–Response: A Theoretical Framework to Explain Drivers' Interactions with Roadway Hazards. *Safety*, *7*(2), 29. https://doi.org/10.3390/safety7020029

Borowsky, A., Oron-Gilad, T., & Parmet, Y. (2009). Age and skill differences in classifying hazardous traffic scenes. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(4), 277–287. https://doi.org/10.1016/j.trf.2009.02.001

Braitman, K. A., Kirley, B. B., McCartt, A. T., & Chaudhary, N. K. (2008). Crashes of novice teenage drivers: Characteristics and contributing factors. *Journal of Safety Research*, *39*(1), 47-54. https://doi.org/10.1016/j.jsr.2007.12.002

Crundall, D. (2016). Hazard prediction discriminates between novice and experienced drivers. *Accident Analysis & Prevention*, *86*, 47–58. https://doi.org/10.1016/j.aap.2015.10.006

Crundall, D., Chapman, P., Trawley, S., Collins, L., van Loon, E., Andrews, B., & Underwood, G. (2012). Some hazards are more attractive than others: Drivers of varying experience respond differently to different types of hazard. *Accident Analysis & Prevention*, *45*, 600–609. https://doi.org/10.1016/j.aap.2011.09.049

Durbin, D. R., McGehee, D. V., Fisher, D., & McCartt, A. (2014). Special considerations in distracted driving with teens. *Annals of advances in automotive medicine. Association for the Advancement of Automotive Medicine. Annual Scientific Conference*, *58*, 69–83.

Eimer, M. (1998). The lateralized readiness potential as an on-line measure of central response activation processes. *Behavior Research Methods, Instruments, & Computers*, *30*(1), 146-156.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*(1), 32-64. https://doi.org/10.1518/001872095779049543

Fisher, D. L., Pollatsek, A. P., & Pradhan, A. (2006). Can novice drivers be trained to scan for information that will reduce their likelihood of a crash?. *Injury Prevention*, *12*(1), 25-29. http://dx.doi.org/10.1136/ip.2006.012021

Fisher, D. L., Pradhan, A. K., Pollatsek, A., & Knodler, M. A. (2007). Empirical Evaluation of Hazard Anticipation Behaviors in the Field and on Driving Simulator Using Eye Tracker. *Transportation Research Record: Journal of the Transportation Research Board*, *2018*(1), 80–86. https://doi.org/10.3141/2018-11

Fisher, D. L., Pradhan, A. K., Pollatsek, A., & Knodler Jr, M. A. (2007). Empirical evaluation of hazard anticipation behaviors in the field and on driving simulator using eye tracker. *Transportation Research Record*, *2018*(1), 80-86. https://doi.org/10.3141/2018-11

Groeger, J.A. (2000). *Understanding driving: Applying cognitive psychology to a complex everyday task.* Psychology Press.

Groeger, J.A., Field, D., & Hammond, S. (1998). R*isk hazard perception and perceived control. Vol. 2: Computerised assessments of drivers' skills: relationships between measures* (Unpublished Project Report No. TT/124/98: DPU 9/31/14. Crowthorne, UK: Transport Research Laboratory.

He, D., & Donmez, B. (2022). The influence of visual-manual distractions on anticipatory driving. *Human Factors*, *64*(2), 401–417. https://doi.org/10.1177/0018720820938893

Horswill, M. S., & McKenna, F. P. (2004). Drivers' hazard perception ability: Situation awareness on the road. In *A Cognitive Approach to Situation Awareness*.

Insurance Institute for Highway Safety (IIHS) (2021). Fatality Facts 2019: Teenagers. Highway Loss Data Institute; March 2021.

Kakei, S., Hoffman, D. S., & Strick, P. L. (2001). Direction of action is represented in the ventral premotor cortex. *Nature Neuroscience*, *4*(10), 1020-1025. https://doi.org/10.1038/nn726

Katila, A., Keskinen, E., & Hatakka, M. (1996). Conflicting goals of skid training. *Accident Analysis & Prevention*, *28*(6), 785–789. https://doi.org/10.1016/S0001-4575(96)00045-0

Kilner, J. M., Vargas, C., Duval, S., Blakemore, S. J., & Sirigu, A. (2004). Motor activation prior to observation of a predicted movement. *Nature Neuroscience*, *7*(12), 1299-1301. https://doi.org/10.1038/nn1355

Krishnan, A., Samuel, S., Yamani, Y., Romoser, M. R. E., & Fisher, D. L. (2019). Effectiveness of a strategic hazard anticipation training intervention in high risk scenarios. *Transportation Research Part F: Traffic Psychology and Behaviour*, *67*, 43–56. https://doi.org/10.1016/j.trf.2019.10.004

Loeb, H. S., Kandadai, V., McDonald, C. C., & Winston, F. K. (2015). Emergency braking in adults versus novice teen drivers: response to simulated sudden driving events. *Transportation Research Record*, *2516*(1), 8-14.

McKnight, A. J., & McKnight, A. S. (2003). Young novice drivers: careless or clueless? *Accident Analysis & Prevention*, *35*(6), 921–925. https://doi.org/10.1016/S0001-4575(02)00100-8

Meir, A., Borowsky, A., & Oron-Gilad, T. (2014). Formation and Evaluation of Act and Anticipate Hazard Perception Training (AAHPT) Intervention for Young Novice Drivers. *Traffic Injury Prevention*, *15*(2), 172–180. https://doi.org/10.1080/15389588.2013.802775

Mourant, R. R., & Rockwell, T. H. (1972). Strategies of Visual Search by Novice and Experienced Drivers. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *14*(4), 325–335. https://doi.org/10.1177/001872087201400405

Muttart, J.W. & Fisher, D.L. (2017). Hazard mitigation responses by novice and experienced drivers. In D.L. Fisher, J.K. Caird, W.J. Horrey, & L.M. Trick (Eds.), *Handbook of Teen and Novice Drivers* (pp. 85-103)

Muttart, J.W., Fisher, D.L., Pollatsek, A.P., & Marquard, J. (2013). Hazard mitigation when approaching curves. *7th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, Lake George, NY.

Muttart, J. (2015). *Influence of Age, Secondary Tasks and Other Factors on Drivers' Swerving Responses before Crash or Near-Crash Events* (No. 2015-01-1417). SAE Technical Paper.

Muttart, J. W., Dinakar, S., Fisher, D. L., Garrison, T. M., & Samuel, S. (2019). Evaluation of a Training Intervention to Improve Novice Drivers' Hazard Mitigation When Approaching Left Turn Scenarios. *Transportation Research Record: Journal of the Transportation Research Board*, *2673*(12), 474–484. https://doi.org/10.1177/0361198119860484

NHTSA. (2019). *Traffic Safety Facts, Young Drivers* (No. DOT HS 812 4753) (p. 2).

Pashler, H., & Baylis, G. C. (1991). Procedural learning: I. Locus of practice effects in speeded choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17*(1), 20–32. https://doi.org/10.1037/0278-7393.17.1.20

Plumert, J. M., Reyes, M., O'Neal, E. E., Vecera, S., Allen, S., & McGehee, D. V. (2021). *Extended Evaluation of Training Programs to Accelerate Hazard Anticipation*

Skills in Novice Teens Drivers (No. UI-2-Y2). Safety Research Using Simulation (SAFER-SIM) University Transportation Center.

Pollatsek, A., Narayanaan, V., Pradhan, A., & Fisher, D. L. (2006). Using eye movements to evaluate a PC-based risk awareness and perception training program on a driving simulator. *Human Factors*, *48*(3), 447-464. https://doi.org/10.1518/001872006778606787

Pradhan, A.K. & Crundall, D. (2017). Hazard avoidance in young drivers: Definitions and a framework. In D.L. Fisher, J.K. Caird, W.J. Horrey, & L.M. Trick (Eds.), *Handbook of Teen and Novice Drivers* (pp. 61-74). https://doi.org/10.17077/drivingassessment.1625

Pradhan, A. K., Hammel, K. R., DeRamus, R., Pollatsek, A., Noyce, D. A., & Fisher, D. L. (2005). Using Eye Movements To Evaluate Effects of Driver Age on Risk Perception in a Driving Simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *47*(4), 840–852. https://doi.org/10.1518/001872005775570961.

Pradhan, A. K., Pollatsek, A., Knodler, M., & Fisher, D. L. (2009). Can younger drivers be trained to scan for information that will reduce their risk in roadway traffic scenarios that are hard to identify as hazardous?. *Ergonomics*, *52*(6), 657-673. https://doi.org/10.1080/00140130802550232

Rizzolatti, G., & Craighero, L. (1998). From spatial attention to attention to objects: An extension of the premotor theory of attention*.* *Revue de Neuropsychologie*, *8*(1), 155-174.

Sahar, Y., Elbaum, T., Wagner, M., Musicant, O., Hirsh, T., & Shoval, S. (2021). Grip force on steering wheel as a measure of stress. *Frontiers in Psychology*, *12*, 617889. https://doi.org/10.3389/fpsyg.2021.617889

Sanders, A. F. (1990). Issues and trends in the debate on discrete vs. continuous processing of information. *Acta Psychologica*, *74*(2-3), 123-167. https://doi.org/10.1016/0001-6918(90)90004-Y

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica*, *30*, 276-315. https://doi.org/10.1016/0001-6918(69)90055-9

Strayer, D. L., & Fisher, D. L. (2016). SPIDER: A Framework for Understanding Driver Distraction. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *58*(1), 5–12. https://doi.org/10.1177/0018720815619074

Taylor, T., Masserang, K., Pradhan, A., Divekar, G., Samuel, S., Muttart, J., … Fisher, D. (2011). Long-Term Effects of Hazard Anticipation Training on Novice Drivers Measured on the Open Road. In *Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design* (pp. 187–194). Olympic Valley-Lake Tahoe, California, USA. https://doi.org/10.17077/drivingassessment.1396

Tefft, B.C. (2017). *Rates of Motor Vehicle Crashes, Injuries and Deaths in Relation to Driver Age, United States, 2014-2015* (Research Brief). Washington, D.C.: AAA Foundation for Traffic Safety.

Thomas, F. D., Rilea, S. L., Blomberg, R. D., Peck. R. C., & Korbelak, K. T. (2016, January). Evaluation of the safety benefits of the risk awareness and perception training program for novice teen drivers (Report No. DOT HS 812 235). Washington, DC: National Highway Traffic Safety Administration.

Unverricht, J., Samuel, S., & Yamani, Y. (2018). Latent Hazard Anticipation in Young Drivers: Review and Meta-Analysis of Training Studies. *Transportation Research Record*, 0361198118768530. https://doi.org/10.1177/0361198118768530

Verwey, W. B. (1994). Evidence for the development of concurrent processing in a sequential keypressing task. *Acta Psychologica*, *85*(3), 245-262.

Wong, A. L., Haith, A. M., & Krakauer, J. W. (2015). Motor planning. *The Neuroscientist*, *21*(4), 385-398. https://doi.org/10.1177/1073858414541484

Yahoodik, S., & Yamani, Y. (2021). Effectiveness of risk awareness perception training in dynamic simulator scenarios involving salient distractors. *Transportation Research Part F: Traffic Psychology and Behaviour*, *81*, 295–305. https://doi.org/10.1016/j.trf.2021.06.009

Yamani, Y., Samuel, S., Knodler, M. A., & Fisher, D. L. (2016). Evaluation of the effectiveness of a multi-skill program for training younger drivers on higher cognitive skills. *Applied Ergonomics*, *52*, 135–141. https://doi.org/10.1016/j.apergo.2015.07.005

Yamani, Y., Bıçaksız, P., Palmer, D., Hatfield, N., & Samuel, S. (2018). Evaluation of the Effectiveness of a Gaze-Based Training Intervention on Latent Hazard Anticipation Skills for Young Drivers: A Driving Simulator Study. *Safety*, *4*(2), 18. https://doi.org/10.3390/safety4020018

Yamani, Y., Samuel, S., Yahoodik, S., Fisher, D.L. (2021). Identifying and remedying failures of hazard anticipation in novice drivers. *Theoretical Issues in Ergonomics Science*. Advanced Online Publication. https://doi.org/10.1080/1463922X.2021.1971323

Zhang, T., Hajiseyedjavadi, F., Wang, Y., Samuel, S., Qu, X., & Fisher, D. (2018). Training interventions are only effective on careful drivers, not careless drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *58*, 693-707. https://doi.org/10.1016/j.trf.2018.07.004

APPENDIX A

MOTION SICKNESS SUSCEPTIBILITY QUESTIONNAIRE SHORT-FORM (MSSQ-SHORT)

This questionnaire is designed to find out how susceptible to motion sickness you are, and what sorts of motion are most effective in causing that sickness. Sickness here means feeling queasy or nauseated or actually vomiting.

1. **As a child (before age 12),** how often you **felt sick or nauseated** (tick boxes).

	Not Applicable – Never Traveled	Never Felt Sick	Rarely Felt Sick	Sometimes Felt Sick	Frequently Felt Sick
Cars					
Buses					
Trains					
Aircraft					
Ships					
Swings in playground					
Roundabouts in playgrounds					
Big Dipper, funfair rides					

2. Over the last 10 years, how often have you felt sick or nauseated (tick boxes):

	Not Applicable – Never Traveled	Never Felt Sick	Rarely Felt Sick	Sometimes Felt Sick	Frequently Felt Sick
Cars					
Buses					
Trains					
Aircraft					
Ships					
Swings in playground					
Roundabouts in playgrounds					
Big Dipper, funfair rides					

APPENDIX B

SIMULATOR SICKNESS QUESTIONNAIRE (SSQ)

No______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

APPENDIX C

DRIVING HISTORY QUESTIONNAIRE

Participant ID:

(Research Admin. use only)

APPLIED COGNITIVE PERFORMANCE LAB
DRIVING HISTORY QUESTIONNAIRE

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

Section 1: Demographics

Gender: ☐ Male ☐ Female

Date of Birth: (Month / Day / Year): _______ / _______ / _______ **Age:** ___________

Race / Ethnicity: (check all that apply)
☐ Black / African American
☐ Caucasian
☐ Hispanic / Latino
☐ Asian
☐ American Indian / Native Alaskan
☐ Other

Have you participated in a study at this laboratory in the past? ☐ Yes ☐ No

Section 2: Driving History

Approximately how long have you had your driver's license? _______ years _______ months

About how many miles did you drive since your licensure? ____________ miles

Does your license require you to wear glasses or contacts while driving? ☐ Yes, eyeglasses ☐ Yes, contacts ☐ No

Do you have any other restrictions on your driver's license? ☐ Yes ☐ No

If yes, please describe: ____

Are you currently on any over-the-counter or prescription medications that make it difficult to drive? ☐ Yes ☐ No

If yes, please describe:

In the past three months, have you text messaged while driving? ☐ Yes ☐ No

Participant ID:

(Research Admin. use only)

Section 2: Driving History (continued)

Do you think text messaging while driving could affect your driving performance? ☐ Yes ☐ Maybe ☐ No

How frequently do you text message in a day? ☐ Over 20 ☐ 10 - 20 ☐ 5 - 10 ☐ Less than 5 ☐ Never

Within the last three years, have you had any moving violations? ☐ Yes ☐ No

If so, what type and how many?	☐ Speeding	How many times?
	☐ Running red light	How many times? _____
	☐ Running stop sign	How many times? _____
	☐ Failure to yield	How many times? _____
	☐ Other	How many times?

Within the last three years, have you been involved
in any automobile crashes? ☐ Yes ☐ No

If so, what type of crashes(s)?	☐ Head-on collision (front of car to front of car contact)
(Please check all that apply)	☐ Rear-end collision (front of car to rear of car contact)
	☐ Side impact or angled collision (front of car to side of car contact)
	☐ Sideswipe (door to door contact)
	☐ Single car accident (struck tree, sign, pedestrian)
	☐ Multiple car accident (more than two cars involved)
	☐ Other
	☐ I don't remember

Please describe each of these crashes in a few sentences below.

____

____

____

____

APPENDIX D

BAYESIAN DESIGN ANALYSIS

Effect size taken from the difference in hazard anticipation between young and older drivers (Pradhan et al., 2005), of $d = 1.23$.

In a Bayesian power analysis simulation (using *BayesFactor* in R), at n = 20, 79% of simulations showed effects of $B_{10} > 10$.

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2022 -present Engineering Psychologist (Student Trainee), Volpe National Transportation Systems Center, Remote
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PUBLICATIONS

Glassman, J., **Yahoodik, S.,** Samuel, S., Young, J., Knodler, M. K., Zhang, T., ... & Yamani, Y. (2022). Booster dose of attention training program for young novice drivers: a longitudinal driving simulator evaluation study. *Human Factors*, 00187208221109993.

Yahoodik, S. & Yamani, Y. (2021). Effectiveness of risk awareness perception training in dynamic simulator scenarios involving salient distractors. *Transportation Research: Part F*. *81*, 295-305.

Yamani, Y., Samuel, S., **Yahoodik, S**., & Fisher, D. L. (2021). Identifying and remedying failures of hazard anticipation in novice drivers. *Theoretical Issues in Ergonomics Science*, 1-14.

Samuel, S., **Yahoodik, S**., Yamani, Y., Valluru, K., & Fisher, D. (2020). Ethical decision making behind the wheel -A driving simulator study. *Transportation Research Interdisciplinary Perspectives, 5,* 100147.