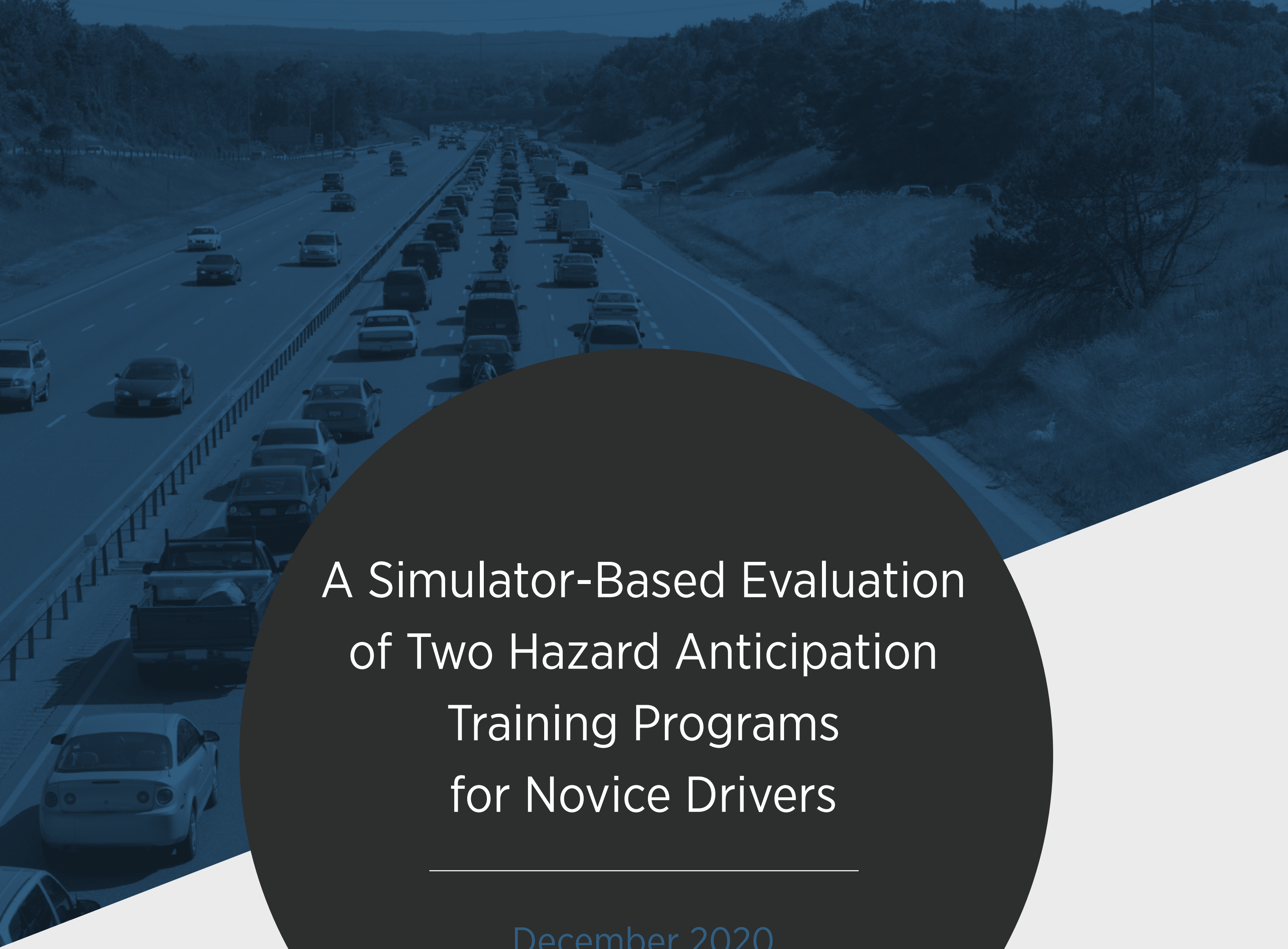

A Simulator-Based Evaluation of Two Hazard Anticipation Training Programs for Novice Drivers

December 2020

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AAA Foundation for Traffic Safety

Title

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for Novice Drivers

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Foreword

A focus of our work at the AAA Foundation for Traffic Safety—*saving lives through research and education*—is providing newly licensed drivers with skills necessary to share the road safely with other road users. A large body of past research by the AAA Foundation and others has shown that young novice drivers crash at higher rates than drivers of any other age—a fact which may be due, at least in part, to their underdeveloped ability to anticipate potential hazards in the driving environment.

In an effort to reduce the risks for this vulnerable population of road users, the AAA Foundation previously supported exploratory research to develop two prototype tools that new drivers could use to strengthen their hazard anticipation and related skills from the comfort and safety of their home. This report presents an evaluation of the effects of these two prototype training tools on young novice drivers' responses to potential hazards in a simulated driving environment. This report should be a useful reference for researchers as well as for practitioners involved in the training of young novice drivers.

C. Y. David Yang, Ph.D.

Executive Director
AAA Foundation for Traffic Safety

About the Sponsor

AAA Foundation for Traffic Safety
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Founded in 1947, the AAA Foundation for Traffic Safety in Washington, D.C., is a nonprofit, publicly supported charitable research and education organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, individual members, AAA-affiliated insurance companies, and other organizations or sources.

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List of Acronyms

AAAFTS	AAA Foundation for Traffic Safety
ACCEL	Accelerated Curriculum to Create Effective Learning
AOI	Area of Interest
CI	Confidence Interval
ICC	Intraclass Correlations
IRB	Institutional Review Board
NADS	National Advanced Driving Simulator
PALM	Perceptual Adaptive Learning Module
OR	Odds Ratio
SAFER-SIM	Safety Research using Simulation
UTC	University Transportation Center

Executive Summary

Young novice drivers are involved in motor vehicle crashes at vastly higher rates than experienced drivers. Previous studies have suggested that elevated crash rates of inexperienced drivers are attributable at least in part to underdeveloped skills in identifying and responding to latent hazards in the driving environment. In past research, the AAA Foundation for Traffic Safety sponsored the development of two prototype computer-based, self-administered training programs that sought to improve novice drivers' ability to detect and respond to hazards on the road: the Perceptual and Adaptive Learning Module (PALM) and the Accelerated Curriculum to Create Effective Learning (ACCEL).

The purpose of the current study was to evaluate the effects of those programs on various measures of newly licensed young drivers' attentional allocation and driving performance after six weeks of unsupervised driving. The study employed a pre-post study design in which 109 study participants' driving performance and eye movement behaviors were examined while they drove in a driving simulator before they received training and again six weeks after training. Participants were 15- and 16-year-old novice drivers with no more than two weeks of unsupervised driving experience. Participants were assigned at random to receive the PALM training or the ACCEL training, or to a control group that received no training.

After reviewing both training programs, the research team developed simulated drives that consisted of urban, residential, and rural driving environments in which selected hazard scenarios were embedded. Hazard scenarios consisted of elements that had the potential to pose a threat to the participant driver but did not actually materialize into a full threat. Each unique study drive presented the same number of hazards, though the hazards were presented in a different order in each drive and extraneous characteristics changed from one drive to the next.

During the first study visit, all participants completed a baseline drive in the NADS-2 simulator while wearing a head-mounted eye tracker. After this baseline drive, participants then completed their assigned training program.

For the next six weeks the participants accumulated real-world driving experience. During this time, they completed a weekly survey to report their miles driven, trip destinations, and driving conditions. After six weeks, participants returned to complete a second simulated drive in which the same skills were again assessed using slightly different simulated driving scenarios.

Measures used to evaluate the effects of the training programs included participants' eye movements (e.g., time to first glance toward locations of potential hazards, number of glances, and total looking time) and driving behavior (e.g., accelerator release, change in speed or lateral position) in response to the potential hazards. The effects of the training were estimated by comparing the changes in these measures from before the first study visit to the second among the trained participants relative to the control group.

Overall, few statistically significant differences in attentional allocation or driving performance measures were observed in association with the training. Participants who received one of the training programs showed improvement on one or more measures in

many of the driving scenarios examined; however, most of these improvements were not significantly larger than those exhibited by the control group. In some driving scenarios examined, there were substantial chance differences between groups in pre-training baseline performance. These measures often converged after training; however, it was unclear whether this represented a training effect, random variation, or an effect of additional driving experience that participants accrued between their first and second drives in the simulator.

It is possible that the training influenced neither participants' attentional allocation nor driving performance; however, other explanations are also possible. The training might have had some effects that were obscured by the wide variability in performance between the study participants. It is also possible that the training improved the performance of a subset of participants but not all of them. Detecting such subgroup effects statistically would likely require a larger study. Finally, it is also possible that effects might not manifest themselves immediately but could become observable after subjects accrue additional driving experience.

Although this study does not provide evidence of efficacy of these programs, results should not be construed as evidence of a lack of efficacy. Components of the ACCEL program, in particular, have shown significant positive effects in other studies. Further research is needed to understand how or whether such training programs affect new drivers' performance and safety.

Introduction

Upon earning a provisional driver's license, crash rates among young novice drivers immediately undergo a sharp increase (Mayhew et al., 2003; Tefft, 2017), and then begin to decline quickly with increased driving experience (Foss et al., 2011). One factor that may play an important role in safe driving behavior is perceptual expertise, or skill in efficiently and effectively responding to perceptual information about hazards in the roadway environment. Recently, the AAA Foundation for Traffic Safety sponsored the creation of two training programs designed to speed the development of these skills in young novice drivers: Perceptual Adaptive Learning Module (PALM) and Accelerated Curriculum to Create Effective Learning (ACCEL). The purpose of the current study was to investigate whether these programs would help inexperienced drivers to improve certain aspects of safety-relevant driving skills more rapidly than they would improve on their own without the training through the acquisition of real-world driving experience.

Perceptual Adaptive Learning Module (PALM)

The Perceptual and Adaptive Learning Model (PALM; Lerner et al. 2017) is a computer-based training program intended to help novice drivers acquire the perceptual expertise needed to identify potential roadway hazards without hours of on-road exposure. Adaptive, perceptual learning has been shown to rapidly increase skill attainment in a variety of domains (e.g., Kellman, 2013; Massey et al., 2013), by optimizing the extraction of information through long-lasting improvements in perception and pattern recognition (Gibson, 1971; Goldstone, 1998; Kellman & Massey, 2013). The PALM for novice drivers is a computer-based program that employs adaptive learning to optimize the efficiency of perceptual learning by presenting many short video episodes in which the learner sees and reacts to scenarios upon detection of a potential hazard unfolding. Six categories of hazard, each with 10 exemplars, are represented in the program:

1. Anticipating that another vehicle on the road may move into your path
2. Anticipating that a vehicle directly ahead may slow severely or stop
3. anticipating that someone or something off the road might move into the road
4. Recognizing that something about the road ahead may force you to change your planned path
5. Recognizing where something significant may be obscured from view
6. Recognizing the presence of an emergency vehicle in the area that might cause conflicts

The PALM program consists of three training trial types: "watch," "respond," and "no event." After watching each event, users must categorize the initial cause of the potential hazard based on the clues provided in the video. For "watch" trials, users watch the clip from beginning to end and then select what initiated the hazard from a multiple-choice list. "Respond" trials require the user to press the space bar when they have identified a potential hazard followed by the selection of what triggered the hazard and again indicate what initiated the hazard from the multiple-choice list. A screenshot from a "respond" trial is shown in Figure 1. "No event" trials are similar to watch trials; however, no hazard is present in the videos. The user then categorizes the initial cause of the potential hazard from a list of answer choices, which are always the same:

1. Another vehicle moving on this road is likely to move suddenly into your path.
2. The vehicle directly ahead of you is likely to slow sharply or stop.
3. Someone or something you can see off the road or on the roadside may move into the road.
4. Something about the road ahead of you may force you to change your planned path.
5. Something significant may be obscured from your direct view.
6. An emergency vehicle in the area might cause conflicts to occur.
7. Don’t know.

The program uses an algorithm that considers the accuracy and speed of users’ responses to prioritize categories of learning that are tailored to the needs of the user to present trials from across the six categories. When the user demonstrates mastery of a category, trials of that type are no longer presented. To complete the training program, the user must master all six categories.

A small usability study was conducted with six drivers, aged 18 to 19, who held provisional licenses. On average it took the participants 100 minutes to complete the PALM and they regarded the training module positively (Lerner et al., 2017).

Figure 1. Screen shot from a respond trial in the PALM training.

Accelerated Curriculum to Create Effective Learning (ACCEL)

ACCEL (Fisher et al., 2017), a PC-based training program, was developed using Microsoft PowerPoint. Visual Basic for Applications was also used to provide additional user interaction functions to the program. The ACCEL program was developed to train novice drivers on three main skills: hazard anticipation (when and where hazards may appear), hazard mitigation (what action to take when a potential hazard has been identified), and attention maintenance (how a driver divides their attention between driving and a secondary task). Each skill is then broken down by strategic and tactical skill. Strategic training focuses on skills that should be used prior to the potential hazard materializing, whereas tactical training is centered on skills to be used “when a hazard may be imminent.”

Training was broken down into blocks and presented in this order:

1. Strategic hazard anticipation
2. Tactical hazard anticipation
3. Strategic hazard mitigation
4. Tactical hazard mitigation
5. Strategic attention maintenance
6. Tactical attention maintenance

These skills are presented in the context of eighteen separate scenarios based on three different types: intersections, rear-end, and curves.

The aim of the program is for users to acquire the identified skills using an active method by which they are expected to make mistakes, receive mentoring to help them understand the correct response, and finally achieve mastery. When presented with a scenario, the program assumes that novice drivers are unfamiliar with the potential hazard being presented. In the hazard anticipation scenarios, users watch an animation and are instructed to click on the area where a hazard would appear. Similarly, hazard mitigation scenarios present the user with an animation of the hazard unfolding, but rather than identifying where the hazard is, users must indicate how they would evade the hazard. In either scenario type, if the user incorrectly guesses the area of interest or the evasion action three times, the program provides the user with the appropriate response, as shown in Figure 2. To conclude the sequence for each skill, the user is presented with the scenario a final time to ensure mastery. ACCEL also includes a module designed to train the user to avoid looking away from the forward roadway for longer than 2 seconds in a single glance.

Figure 2. Screenshot from the ACCEL training program.

An evaluation of ACCEL was conducted previously with 50 young drivers aged 16 to 18 with less than six months of independent driving experience. Immediately after completing the ACCEL training, the participants completed an evaluation drive in a driving simulator. Their performance on the six skills was compared to the performance of a group of 25 young drivers who were exposed to a placebo program before completing the simulator drive. The ACCEL-trained drivers performed significantly better than the placebo group on all six of the skills (Fisher et al., 2017).

Objective

The purpose of the current study was to evaluate how the PALM or ACCEL training affected various measures of attentional allocation and driving performance for newly licensed young drivers when they encountered hazard scenarios in a driving simulator.

Methods

Study design

This study aimed to evaluate the effectiveness of the PALM and ACCEL programs using a pre-test–post-test experimental design with each participant randomly assigned to either PALM training, ACCEL training, or Control (no training) condition. All participants completed an experimental drive in the simulator, which served as the pre-test baseline, close to the time they began driving independently. Then those assigned to the PALM and ACCEL conditions completed the training program. After six weeks of driving experience, each participant completed a second simulator drive. Because each participant served as his/her own control, this design is a powerful test of change in hazard anticipation skills and driving performance that occurs with training plus normal driving experience compared to only normal driving experience.

Participants

Teen drivers aged 15 and 16 years who were planning to obtain a license that allows unsupervised driving and had no previous unsupervised driving experience were recruited for this study. Iowa's minimum age for intermediate licensure is 16, however, young drivers in Iowa can obtain a minor school license (MSL) at age 14.5, which allows them to drive independently between home and school. Teens planning to receive either type of license were eligible for the study. The primary recruitment methods were through area high schools' electronic information sharing systems (e.g., virtual flyers), flyers distributed through driver education classes, the University of Iowa mass email system, and by participating families sharing study information with others. Parents of interested teens completed an eligibility screener online or contacted the study team by email or phone. Teens who had a moped (scooter) license, had more than two weeks of independent driving without a supervisor, did not have normal or corrected-to-normal vision and hearing, required special equipment to drive, or who did not expect to drive unsupervised at least twice a week after licensure were not eligible.

Participants were enrolled from August 2018 through August 2019. A summary is given in Table 1 and enrollment by gender can be found in Appendix A. Most study participants lived within one hour of the University of Iowa. For this study, 83 participants were obtaining a minor school license and 52 were obtaining an intermediate license at the time of enrollment. Only five participants experienced simulator sickness and were not able to continue the study. Four additional participants left the study (one was getting supplementary driving instruction, one did not want to track their mileage, and two teens did not begin driving as planned after completing the first study visit). In all other cases, participants were unable to complete the study due to technical issues with the eye tracker or driving simulator.

Table 1. Enrollment and study completion by Condition and License type.

	Enrolled	Visit 1 Complete	Visit 2 Complete	Complete with Eye Data
ACCEL	45	41	36	35
MSL	27	25	22	22
Intermediate	18	16	14	13
PALM	44	40	36	33
MSL	28	25	24	21
Intermediate	16	15	12	12
Control	46	42	37	35
MSL	28	27	23	22
Intermediate	18	15	14	13
Total	135	123	109	103
MSL	83	77	69	65
Intermediate	52	46	40	38

NADS-2 simulator

The NADS-2 (see Figure 3) is a high-fidelity, fixed-base driving simulator with a full vehicle cab and a 135-degree forward field of view comprised of 5760 x 1200 pixels. The forward scene was projected onto a matte surface concave along both the horizontal and vertical axes by three Panasonic DLP PT-RZ570 series projectors. A SHARP Aquos Quattron liquid crystal TV (61” x 34”) displayed the rearview scene, which the participant viewed through a real rearview mirror. The rear field of view was approximately 34 degrees. Black curtains on the left and right sides of the vehicle cab blocked out other visual information.

Figure 3. NADS-2 driving simulator.

Eye tracker

This study collected eye tracking data using a Dikablis Eye Tracking Glasses Professional headset and Ergoneers D-Lab software. The head unit has a forward-facing scene camera and two eye cameras on mobile swan necks that allow them to be positioned below the participant's eyes (see Figure 4). The head unit was placed on the participant's head with the nose pads on the bridge of the nose and the brow rest against the participant's forehead. In addition to the provided strap, which went around the back of the participant's head, another strap was added across the top of the participant's head, from ear to ear, to bear some of the weight of the unit. The forward scene camera was fitted with a wide-angle lens. An example of the forward view captured in D-Lab with gaze cursor overlaid is shown in Figure 5. The black and white symbols are special markers that the D-Lab software can recognize and can be used to define Areas of Interest (AOIs). These markers were embedded in the forward view and did not move relative to the driver's eyepoint.

Figure 4. Woman wearing Dikablis eye tracking glasses (www.ergoneers.com).

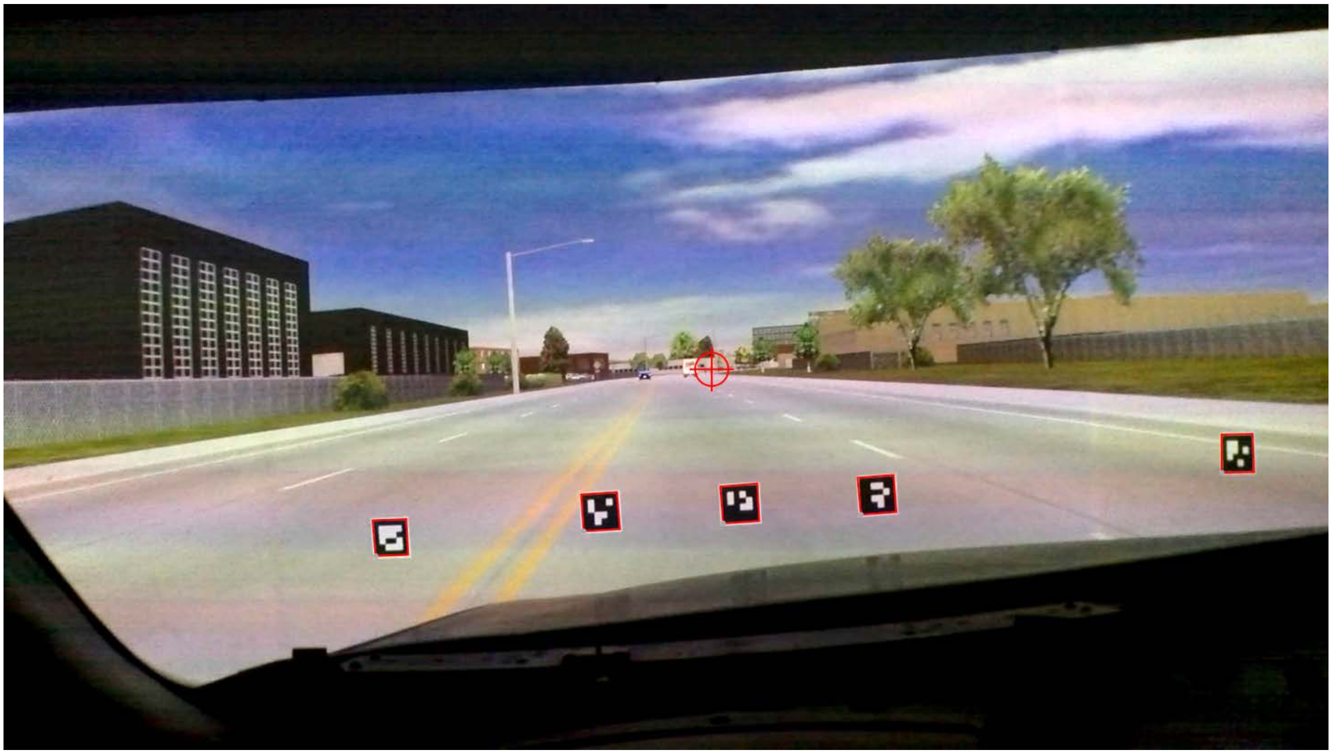

Figure 5. Forward scene camera view captured in D-Lab from the Dikablis eye tracking glasses, with gaze cursor overlay and reference markers.

Simulator drive design

Three different experimental drives with three distinct driving environments were designed for this study.

Each drive began in an urban commercial area with two lanes of traffic in each direction and a speed limit of 30 mph. Some areas were traditional city blocks with street parking and store fronts, and others were business arterials with buildings set back from the roadway, typically behind parking lots and wider sidewalks. The urban section of each drive was organized to position the participant in the desired lane for each event, either through circumstance of a previous event or an audio command to drive in a specific lane.

The second section of the drive comprised a residential area with houses, apartments, and a school zone. The speed limit in this area was 30 mph and there was one lane of traffic in each direction.

The third section of the drive consisted of a rural 2-lane roadway with a speed limit of 45 mph. Finally, to conclude the drive, the roadway passed through a brief residential area at the edge of a town, the speed limit decreased to 30 mph, and the final event was a sharp 90-degree curve.

The duration of the study drive was about 22 minutes. All three study drives had these sections in the same order but the individual roadway segments assembled to create the drive were rearranged within each section. The order of the three drives (A, B, C) themselves was counterbalanced across visit (1, 2, 3) using all 6 possible combinations. The research described in this report is based on two study drives, one performed in visit 1 before completing the training and another performed in visit 2 approximately six weeks after completing training. Participants also completed a third drive in a third visit approximately six months after completing training. The third visit and the associated research was supported by the SAFER-SIM University Transportation Center and will be described in a subsequent report.

Scenario events

Each drive included 25 "events." There are three types of events:

1. Potentially hazardous situations that warrant the participants' attention, which were selected with consideration toward general types of situations presented in the PALM and ACCEL programs.
2. Driving while completing a secondary task with an in-vehicle touchscreen display, with consideration toward the attention maintenance module of ACCEL.
3. Periods of "normal" driving.

The same events were repeated in each of the study drives, occurring in different orders, different locations, or under different circumstances.

Potential hazard events

Within the potentially hazardous situation class of events, there were five categories of events with respect to the training programs, ACCEL and PALM (see Table 2). Events were classified as "near" or "far" to the respective training programs based on the extent to which they were similar to events encountered in those training programs. Events that were represented in both training programs were classified as Near/Near. An event that was represented in one training program but was similar to another event in the other training program was classified as Near/Far.

Table 2. Event categories with respect to the ACCEL and PALM training programs.

Event category	This type of event is…
Near/Near	Included in both the ACCEL and PALM training programs.
ACCEL Near/ PALM Far	Included in the ACCEL program and has some similarity to a PALM event
PALM Near/ ACCEL Far	Included in the PALM program and has some similarity to a ACCEL event
PALM Unique	Included in PALM and nothing in ACCEL is similar
ACCEL Unique	Included in ACCEL and nothing in PALM is similar

Mid-block crosswalk event (Event category: Near/Near)

The participant was driving in the left lane of a city street with two lanes in each direction. Ahead there is a midblock crosswalk with neon yellow signs that indicated there was crosswalk ahead and the location of the crosswalk. A large vehicle was stopped in the right lane in front of the crosswalk, blocking the participant's view of the crosswalk (see Figure 6). Pedestrians could be seen walking on the sidewalk to the right of the large vehicle in the same direction as the participant and were then obscured by the large vehicle. The pedestrians stopped walking and remained on the sidewalk (see Figure 7). The event window began 5 seconds before the pedestrians began walking on the sidewalk, which was when the participant was 500 feet from the crosswalk. The close proximity period began approximately 250 feet from the crosswalk.

Figure 6. Participant's view of the mid-block crosswalk event.

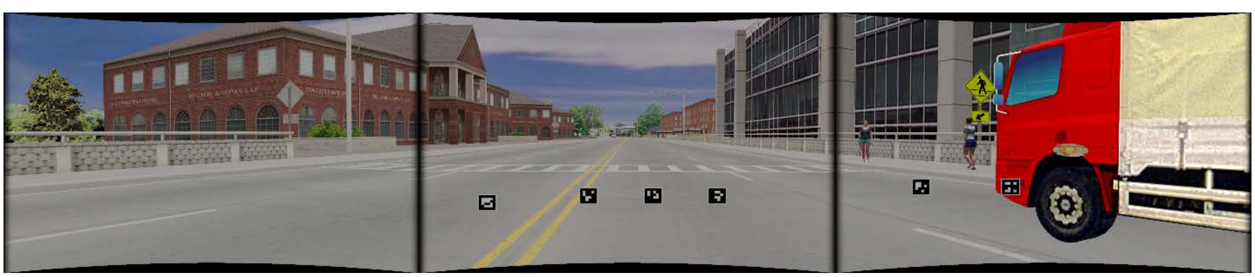

Figure 7. Participant's view of the pedestrians that have been obscured by the stopped vehicle in the mid-block crosswalk event.

Parallel parked car event (Event category: Near/Near)

The participant was driving in the right lane of a city street with two lanes in each direction. Along the right side of the street there were multiple vehicles parallel parked. One of the vehicles was oriented at a slight angle towards the roadway, as though it might pull out. As the participant approached, the vehicle's left turn signal was activated (see Figure 8). Coding of the eye data began as soon as the parallel parked car was visible, at a distance of approximately 700 feet. The close proximity period began 300 feet from the parked car.

Figure 8. Participant's view of the parallel parked car event.

Partial lane obstruction event description (Event category: PALM Unique)

The participant was traveling on a roadway with one lane in each direction. The participant's lane was partially blocked by a vehicle stopped on the side of the street/road (see Figure 9).

Figure 9. Participant's view of one the partial lane obstruction events.

Dynamic object event description (Event category: PALM Unique)

The participant was traveling on a roadway with one lane in each direction. A dynamic object (i.e., a deer, dog, or child) that could dart into the roadway appeared on the right side of the road. The object moved slightly toward the roadway but did not enter (see Figure 10).

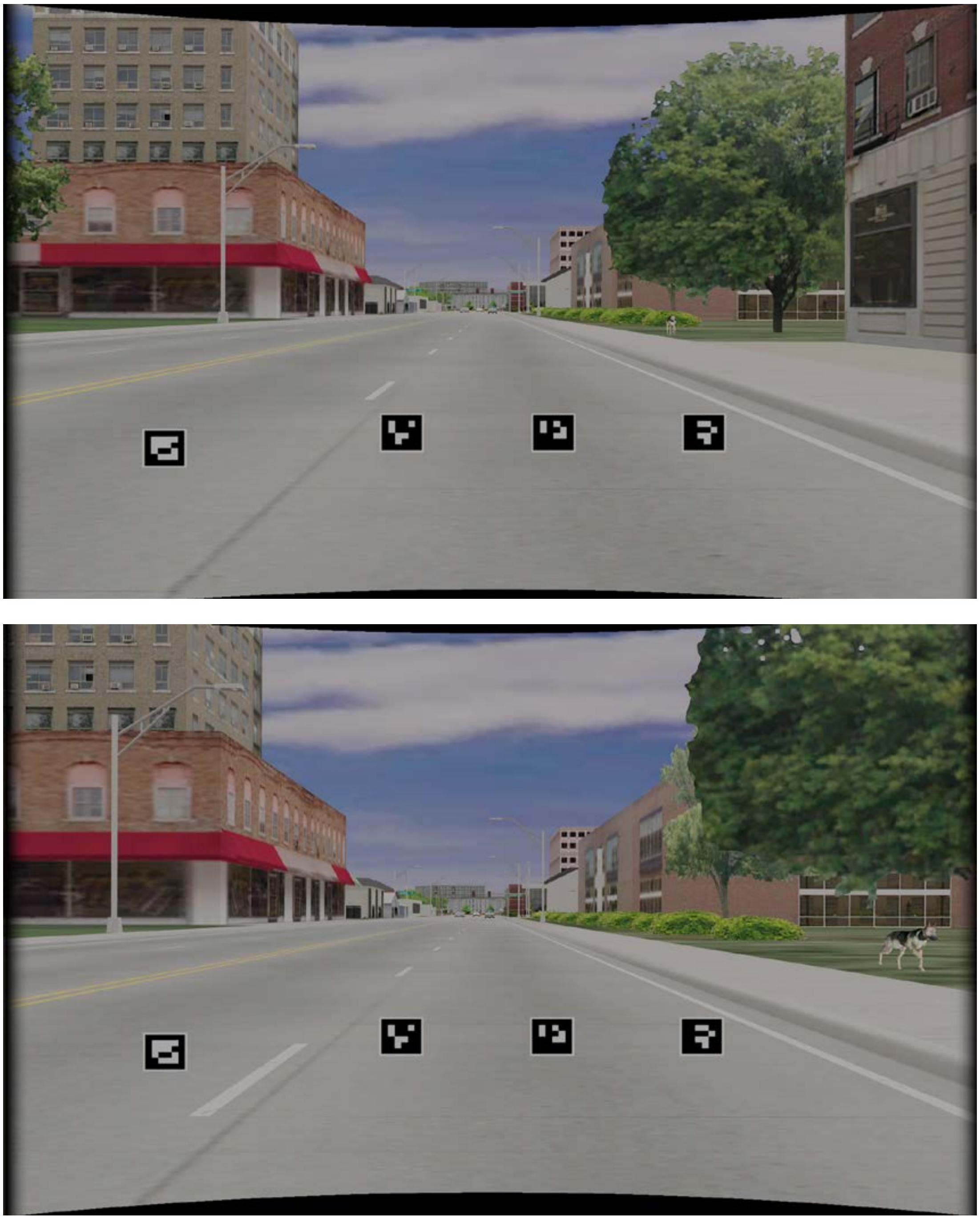

Figure 10. Participant's view of one of the dynamic objects event at two instances.

Potential incursion event description (Event category: PALM Near/ACCEL Far)

The participant was traveling on a roadway where the speed limit was 30 mph. As the participant approached an intersection, a vehicle approached on the cross street from the right. After stopping at the stop sign, the vehicle began to move forward, as though it were going to turn right and enter the roadway in front of the participant, before it comes to a stop again (see Figure 11). The eye data coding window began when the approaching vehicle was visible and the close proximity period began when the vehicle moved forward after stopping.

Figure 11. Participant's view of one the potential incursion events.

Work zone lane closure event description (Event category: Near/Near)

The participant was traveling on a city street with two lanes in each direction and approached a short work zone containing a work vehicle. The lane in which the participant was driving became closed with construction barrels. Two orange warnings signs, first a human silhouette digging with a shovel (not pictured), and then a lane merging sign (see Figure 12, top) which preceded the lane closure (Figure 12, bottom). Any same direction traffic was well ahead or far behind (i.e., visible in rear-view mirror) in order to prevent another vehicle from being in the participant's blind spot.

Figure 12. Participant's view of one of the work zone lane closure events at two instances.

Transition from 4-lane to 2-lane event description (Event category: Near/Near)

The participant was traveling on a city street with two lanes in each direction that transitioned to one lane in each direction when the right lane merged into the left. Two yellow advisory signs preceded the merge (see Figure 13).

Figure 13. Participant's view of the transition from 4-lane to 2-lane event.

<u>90-degree curve (Event category: ACCEL Unique)</u>

The participant was traveling in a residential area with one lane in each direction and was approaching a 90-degree small radius curve to the right with line of sight around the corner obscured. There was a warning sign with the posted advisory speed of 20 mph (see Figure 14, top) followed by a second warning sign without a speed placard (Figure 14, bottom).

Figure 14. Participant's view of the 90-degree curve event at two instances.

Platoon braking (Event category: ACCEL Near/PALM Far)

The participant was driving on a city street with two lanes in each direction. Ahead in the same lane were two vehicles and in the adjacent lane there were five vehicles. After driving in this platoon for about 25 seconds, the brake lights of the third vehicle in the adjacent lane (i.e., the blue-gray vehicle in Figure 15) were illuminated for 1.5 seconds. After about 4.5 seconds, this vehicle's brake lights were illuminated a second time for 1.5 seconds. Immediately after that vehicle's brake lights turned off, the brake lights of the next following vehicle were illuminated for a duration of 2 seconds. Coding of eye glances and driving performance began 3 seconds before the platoon vehicle's brake lights came on the first time and ended 7 seconds after the platoon vehicle's brake lights came on the second time.

Figure 15. Participant's view of the platoon braking event.

Ambulance (Event category: PALM Unique)

The participant was traveling on a city street with two lanes in each direction. An ambulance in emergency status with lights and sirens enters the roadway. An example is shown in Figure 16.

Figure 16. Participant’s view of one of the ambulance events after being overtaken by the ambulance.

Left lane impeded (Event category: Near/Near)

The participant was driving in the right lane of a city street with two lanes in each direction. Ahead in the left lane there were two vehicles, with the lead vehicle traveling at a slower speed and the distance between the lead vehicle and following vehicle was closing (see Figure 17 for an example). The brake lights of the following vehicle were illuminated and the vehicle comes to a stop behind the slowing/stopped lead vehicle.

Figure 17. Participant's view of one of the left lane impeded events.

Intermittent lead vehicle braking (Event category: PALM Unique)

The participant was driving on a city street and was following a lead vehicle, which without warning brakes for 4 seconds. After about 3.5 seconds, it brakes a second time for 3 seconds. After about 4 seconds, it brakes a third time for 3 seconds. The intention of this braking sequence was for it to appear as if the driver of the vehicle ahead were looking for a parking space or looking for the correct place to turn (see Figure 18).

Figure 18. Participant's view of one of the intermittent lead vehicle braking events.

Obscured cross-traffic lane (Event category: ACCEL Near/PALM Far)

The participant was driving on a city street with two lanes in each direction. As the participant approached a signalized intersection with two lanes of cross traffic in each direction, the stoplight cycled to green. In the near lane of cross traffic to the participant's right, a city bus was blocking the participant's view of the far lane of cross traffic on the right. The position of the bus obscured the far lane of cross traffic from the right such that the participant could not see if a vehicle was approaching and could potentially enter the intersection as the participant traveled through (see Figure 19). The eye coding window began when the bus became visible, and the close proximity period began as shown in the figure.

Figure 19. Participant's view of the obscured cross-traffic lane event.

Obscured T-intersection (Event category: ACCEL Near/PALM Far)

The participant was traveling on a street with one lane in each direction. A yellow advisory sign warned of a T-intersection with a cross street to the right (see Figure 20, top). The intersection itself was partly obscured (see Figure 20, bottom). The eye coding window began about 825 feet before the intersection (500 feet before the warning sign) and the close proximity period began 215 feet from the intersection.

Figure 20. Participant's view of one of the obscured T-intersection events at two instances.

Fire station (Event category: PALM Unique)

The participant was traveling in a residential area with one lane of traffic in each direction. A yellow advisory sign indicated there was a fire station ahead. There were no vehicles at the fire station and no activity occurring at the fire station (see Figure 21).

Figure 21. Participant's view of the fire station event.

Secondary tasks events

During each of the study drives, the participant was instructed to complete two different simulated phone tasks using small in-vehicle display with a touch interface. One was a dialing task and the other was a selecting a contact from a list. Before the practice drive, the participant received instructions and practiced doing each task. They were also advised, "All the phone numbers will start with '319'. This is not a test of your memory. If you forget the phone number that was announced, that is OK. Just dial the numbers that you do remember and complete the call anyway." They were instructed to perform each secondary task once during the practice drive and two times each during the study drive (once each in the city portion of the drive and once each in the rural portion).

Each task period began with an alert sound. Then an audio prompt announced the task. For the phone dialing task, the instruction was: "Please dial this number: 319-261-3013." Then touchscreen turned on (see Figure 22) and the phone number was repeated a second time. The participant dialed the phone number, pressed the dial button to connect (see Figure 23) and pressed it again to hang up. For the contact search task, the instruction was: "Please go to Contacts and find 'Donald Duck.'" Then touchscreen turned on and then the contact name was repeated a second time. The participant scrolled through the list to find the name, touched it to connect the call (see Figure 24) and then pressed the button to hang up. After a period of time, the display turned off. A new phone number and a new contact name was given each time the participant was instructed to perform a secondary task. The contact names were organized so that the participant would have to scroll through about seven screens to find the target name in the contact list.

Driving performance was analyzed for the period of time the participant was interacting with the touchscreen. The distribution of time to complete each secondary task is shown in Figure 25. Most participants took at least 10 seconds to perform each task.

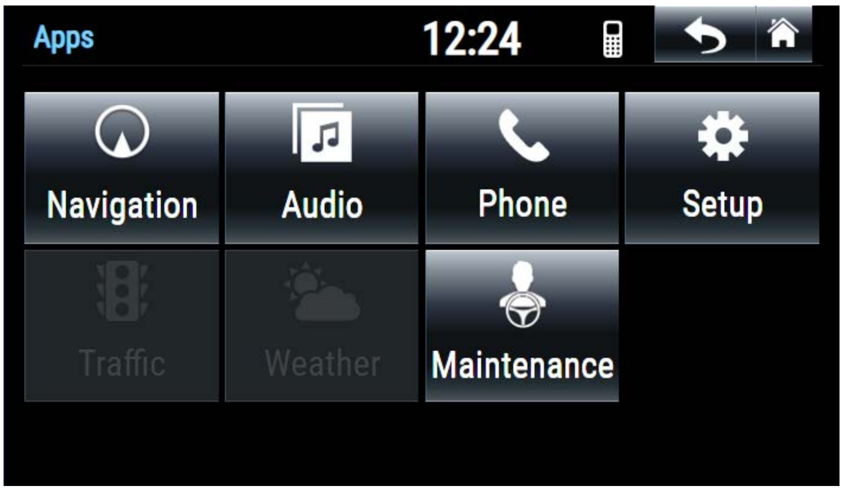

Figure 22. Touchscreen display at the beginning of each secondary task.

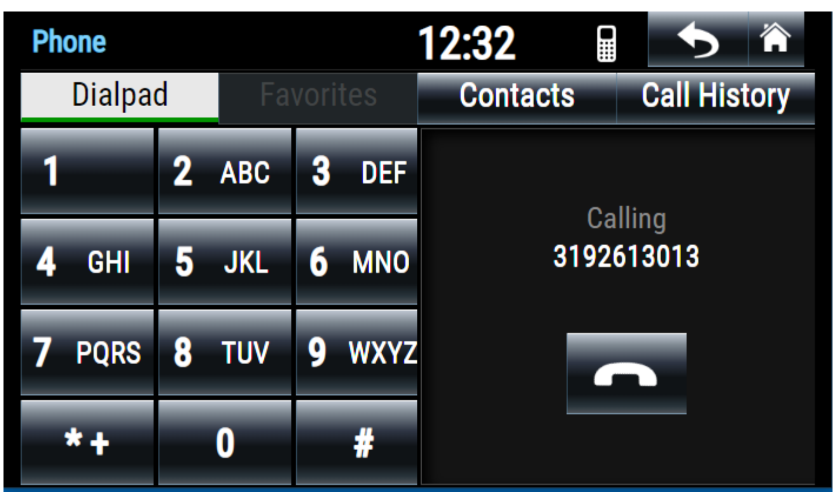

Figure 23. Touchscreen display after connecting a call by dialing.

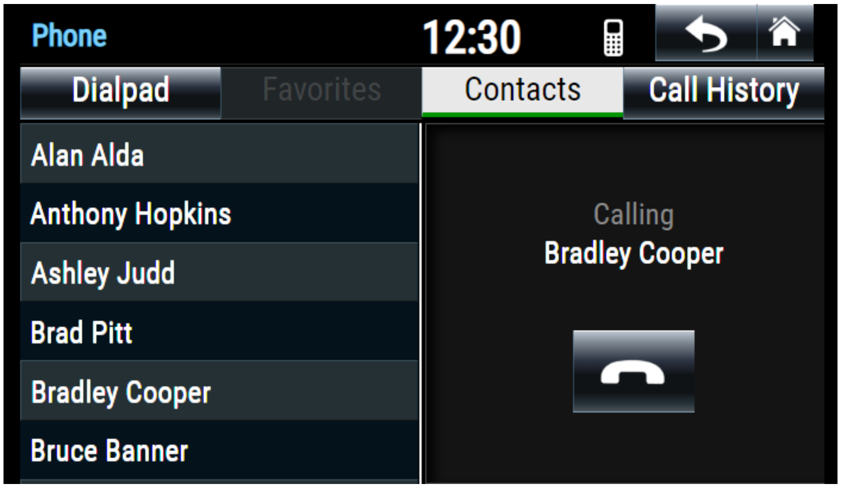

Figure 24. Touchscreen display after connecting a call by selecting a contact.

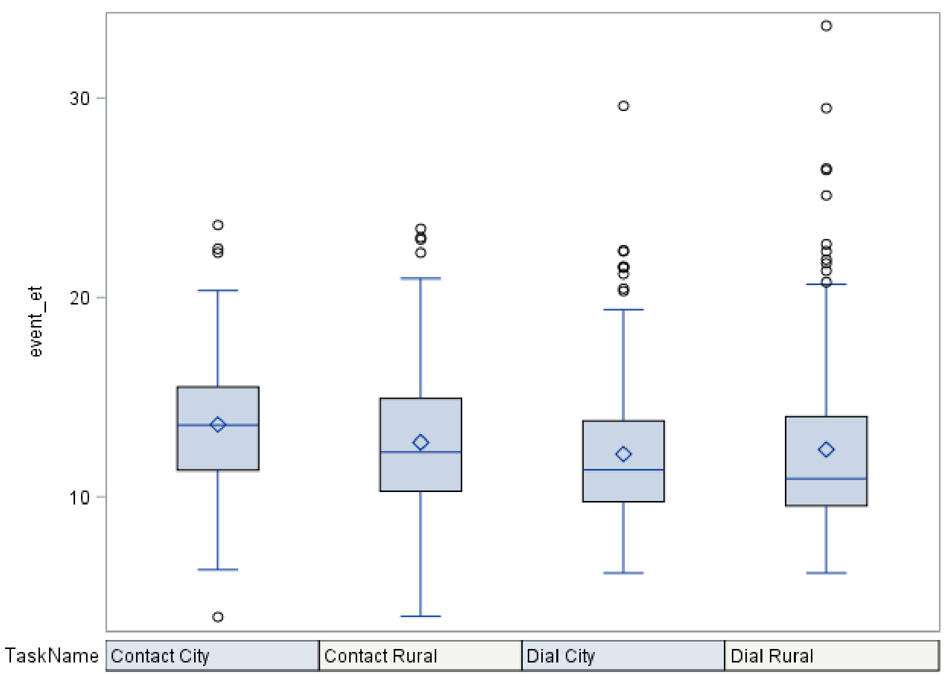

Figure 25. Boxplot of event duration (seconds) for each of the secondary tasks across both study visits.

Normal driving events

The drives also contained periods of driving without potential hazard events or secondary tasks, described in Table 3.

Table 3. Normal driving event descriptions.

School zone	The participant was traveling on a residential street with two lanes in each direction. They approached and traveled through a school zone with a crosswalk and a speed limit of 20 mph (see Figure 26).
4-way stop sign with traffic present	The participant was traveling on a residential street. As they approached a 4-way stop intersection, other vehicles approached the intersection from the opposite direction and the left. Each of these cars turned right and the participant proceeded straight (see Figure 27).
4-way stop sign without traffic	The participant was traveling on a residential street when they encountered a 4-way stop intersection.
Following a lead vehicle	The participant was traveling on a two-lane rural roadway when a same-direction vehicle turned onto the road at least 1000 feet ahead. After maintaining a 4.5 sec time headway for at least 1000 feet, the lead vehicle traveled at a fixed speed of 38 mph for a distance of approximately 4,500 feet before slowing and turning right off the roadway. The participant was discouraged from passing the lead vehicle by the presence of oncoming traffic and double solid yellow lane lines.
Normal urban driving	The participant was traveling on a four-lane commercial roadway with a speed limit of 30 mph for about 3000 feet with no other concurrent event
Normal rural driving	The participant was traveling on a two-lane rural roadway with a speed limit of 45 mph for at least 4000 feet with no other concurrent event/traffic/hazard

Figure 26. Participant’s view of the school zone at two instances.

Figure 27. Participant's view of the 4-way stop intersection with traffic present.

Study visits

Visit 1

At the first study visit, each participant was first asked questions about their licensure type, date the license was obtained, and what date they began driving as a means of verifying study eligibility. Upon verifying eligibility, consent was obtained from the teen and their parent or legal guardian. Following consent, the participant viewed a Power Point presentation that provided information about the NADS-2 driving simulator and then completed a demographic questionnaire via Qualtrics. Then the participant was escorted to the NADS-2, seated in the vehicle cab and asked to adjust the seat to a comfortable position for driving. Then the researcher helped the participant put on the Dikablis glasses head-mounted eye tracker and the eye tracker cameras were adjusted. The researcher read instructions about how to perform the secondary tasks, and the participant practiced using the touch screen and completing the tasks. Finally, a calibration procedure for the eye tracker was completed.

Next each participant completed an 8-minute practice drive. Upon completion of the practice drive, the participant completed a wellness survey to assess whether they had any symptoms of simulator sickness. If the participant reported significant symptoms on the wellness survey (n = 5), the data collection procedures ended. Next the participant completed a 22-minute experimental drive that included the driving environments and hazard scenarios described previously. The wellness survey was administered again after the experimental drive.

Immediately following the experimental drive, all participants except those assigned to the control group completed their randomly assigned training module (PALM or ACCEL). The training programs were administered on a computer located in a quiet room on a 39-inch 1080p HD display.

After the training session, participants completed the post-training survey. In addition to asking the participant to rate their levels of agreement with thirteen statements about the training program (which are listed in Appendix B), they were asked to share what they liked, did not like, and would change about the program.

At the end of Visit 1, all participants received instructions about how to track their weekly driving and were provided with a tracking log in which they were asked to report their miles driven, the conditions in which they drove, and their general destinations (e.g., home, school, other) each week (see Appendix D – Mileage Log). The researcher read a debriefing statement that asked the participants not to discuss details from the study with anyone. It also reminded them that driving in the simulator was not the same as driving in the real world and that performing secondary tasks while driving is very dangerous. Participants received a weekly reminder by either text or email and completed the survey via Qualtrics.

Visit 2

Whenever possible, the second study visit was scheduled so the participant had completed six weeks of independent driving after the first study visit. Upon arrival to the National Advanced Driving Simulator for the second visit, participants reviewed the training Power Point for the driving simulator. Then they were again fitted with the eye tracker, completed the eye tracker calibration procedures, received instructions for the secondary tasks, and completed the 8-minute practice drive. After completing the Wellness Survey and reviewing any symptoms of simulator sickness with the research assistant, the participant completed a different version of the 22-minute experimental drive.

Eye movement data

Eye movement data were collected to assess where drivers were scanning while driving and whether or not they looked at areas associated with potential hazards. While the Dikablis eye tracker collected accurate eye tracking data on the whole, there were some participant drives where the pupil tracking required correction. There were many instances where the participant changed posture or head pose such that the gaze cursor projected into the forward scene was shifted away from the locations they were actually looking. These instances were corrected manually using the D-Lab software.

While D-Lab provides a way of defining AOIs to automate coding of looks to these areas, the research team discovered that this approach did not work well for targets in the dynamic simulated environment. For example, a sign warning of an upcoming lane merge was small in size and centrally located in the scene when it was first visible and then it gradually grew in size and moved right across the screen as the participant drove towards it in the virtual world. Using the software would have required defining multiple AOIs throughout the duration of the event and then verifying the position of each of these AOIs for each participant drive. Thus, the research team coded each event manually. First analysts reviewed both pupil tracking and gaze calibration and made corrections in the Ergoneers D-Lab software. Then analysts coded the eye movements by annotating the start and end of each glance to the target area(s) defined for that event. While glances of all durations were coded, only glances greater than 100ms were analyzed.

For each event, each analyst who was coding eye movements first coded glances for fifteen events (equally distributed among the three study drives A, B, and C). Interrater reliabilities (N = 15) for the continuous variables of time to the first glance, number of glances, and total looking time (and for the midblock crosswalk event, the number of looks left) were calculated using intraclass correlations (ICC) and ranged between ICC = 0.96 and ICC = 0.99. Categorical variables of the area first noticed by participants, if the participant scanned the left side of the crosswalk, and if participants looked to the pedestrians after they were occluded by the stopped vehicle were calculated using Cohen's kappa and ranged between $K = 0.61$ and $K = 0.81$.

Driving performance data

Driving simulator data reduction

The NADS-2 outputs a DAQ file. Data reduction procedures in MATLAB process this raw file and resample the data so all variables were reported at the same rate. A rate of 60 Hz was used for this study. The data included vehicle inputs such as accelerator pedal position, brake pedal force, steering wheel angle, and turn signal; its position in the virtual world, velocity, and acceleration in three dimensions; and lane position. The data also included the position, velocity, and acceleration of every dynamic object simulated in the virtual world, in addition to the button presses and screen touches registered on the in-vehicle touchscreen. Scripts were written in MATLAB to define the window of analysis for each event and then calculate the specified dependent measures.

Driving performance dependent measures

Accelerator release – accelerator release was operationalized as the first point in the event window in which the accelerator pedal position transitioned from above 1% to below 1% (referencing a normalized 0–1 range). After identifying the instant when the study participant released the accelerator, the time from start of event to the release was recorded. The participant vehicle's position at accelerator release was noted, and then the distance the participant vehicle had traveled since the start of the event and the distance it travelled to the end of the event were also calculated.

Brake press – brake press was operationalized as the first point in the event window at which the brake pedal force transitioned from below 1 lbf to above 1 lbf. Once this press was identified, times and distances were calculated in the same manner as for accelerator release.

Minimum speed during the event – minimum vehicle speed recorded during the event window.

Standard deviation of speed – standard deviation of the vehicle speed recorded during the event window.

Lateral position when passing the hazard – lateral position was calculated by adjusting the participant vehicle position to reference the centerline of the driving lane the participant vehicle was in at the beginning of the event. For example, if the participant vehicle moved from the center of the original lane (lateral position of 0) to the center of the adjacent lane to the left, the lateral position was recorded as -12 feet, or 12 feet to the left (all lanes used in in the current study were 12 feet wide). A value less than 0 indicates a position to the left of the center of the starting lane and a value greater than 0 indicates a position to the right of the center of the starting lane.

Standard deviation of lateral position – standard deviation of the lateral position as defined above.

Crossing of lane line for right-hand hazards – when lateral position in the lane was less than -3 feet, this indicated that the left “tires” of the participant vehicle were leaving the lane. The start of the last time that this occurred in the event window was noted for hazards present on the right side of the road (e.g., parallel parked car). When a lane crossing was identified, times and distances were calculated in the same manner as for accelerator release.

Analytical methods

Continuous dependent measures were analyzed using mixed-effects linear regression. In one instance, the continuous measure of distance to the event at lane change was excessively skewed and thus transformed using the natural log prior to analysis. Bivariate measures of the likelihood of accelerator release and brake press were also analyzed using mixed-effects logistic regression. The maximal mixed-effects structure supported by the data included fixed effects of Condition (ACCEL, PALM, Control), Visit (Visit 1, Visit 2), and their interaction. The main effect of Condition was included as a fixed effect in the model not as a means of testing the overall impact of the interventions over both visits, but rather to control for any differences between groups that existed prior to training. A random intercept of participant, which controls for non-repeatable characteristics of the individual, was included to increase the predictive power of the model. Covariates of License Type (Intermediate, Minor School), number of miles driven, participant gender, and study drive (i.e., simulator drive A, B, or C) were included in all models in order to control for their influence on the dependent variables being tested. The model term of primary interest was the Condition x Visit interaction, which represented the average change in the dependent variable from before training to after training within each group. The beta coefficient estimates for the interaction of Condition and Visit, as well as the main effect of Visit within each Condition, are reported. Statistical significance was assessed at the 95% confidence level using two-tailed tests. When presented in tables, statistically significant main effects of Visit within each Condition and Condition × Visit interactions are shown in bold.

Results

This section describes findings from the post-training survey, participant mileage reported between visits 1 and 2, and analysis of selected eye-glance and driving performance measures for each of the driving events. Error bars in the figures representing analytical results indicate the standard error.

Post training survey

Upon completing the assigned training program, participants completed a questionnaire that asked their opinions. The ratings of agreement with statements about the programs are shown in Table 20 and Table 21 in Appendix C – Post training survey results.

For the PALM program, most participants reported that they slightly agreed or agreed that they learned something new (28% and 28%, respectively) and that they were better prepared to anticipate unexpected events on the road (36% and 26%). The participants reported that they agreed (51%) and strongly agreed (21%) that new drivers could learn a lot from the PALM training, though most slightly agreed (41%), agreed (23%), and strongly agreed (18%) that they were already "very aware" of what was being shown in the PALM program. Most of the participants also agreed and slightly agreed that the PALM program was engaging (31% and 28%) and that they enjoyed the program (24% and 29%); however, more than 20% disagreed and strongly disagreed with these statements.

Most strongly disagreed (41%) and disagreed (33%) that PALM was difficult to use. Similarly, 54% agreed and 15% strongly agreed that PALM was a program that most people could easily use without help. However, about one in five slightly disagreed with this statement. A majority agreed (51%) and strongly agreed (28%) that the PALM instructions were clear. Many of the participants said that the PALM training was tiring (38% slightly agree, 13% agree, 18% strongly agree) and too long (26%, 21%, and 21%, respectively), but about 30% disagreed at some level with both these statements. Participants were also similarly divided about preference to complete the program over several sessions or if drivers would benefit from engaging in the training more than once.

Of the ACCEL participants, 32% slightly agreed, 41% agreed, and 12% strongly agreed that they had learned something new and that other new drivers could learn a lot from the program (34%, 32%, and 32%). Forty percent slightly agreed, 26% agreed, and 17% strongly agreed that they were better prepared to anticipate unexpected events on the road. A majority slightly agreed (43%) or agreed (24%) that they were already "very aware" of what was shown in the training program but 24% slightly disagreed. About one-third agreed that the program was engaging but 27% also slightly disagreed with this statement. Overall, the participants slightly agreed (37%) or slightly disagreed (24%) that they enjoyed the program.

Participants seem divided about whether the ACCEL instructions were easy to understand, with 29% slightly disagreeing and 10% disagreeing compared to 17% slightly agreeing, 31% agreeing, and 14% strongly agreeing. Eighty percent agreed at some level that most people could easily use the program without help and 64% disagreed at some level that the program was difficult to use. The greatest proportion of participants slightly agreed that the ACCEL program was tiring (45%) and took too long to complete (38%). Although 29%

said they disagreed with the statement "I would prefer to complete the program over several, shorter training sessions," levels of agreement on this varied widely. Most participants agreed that drivers would benefit from engaging in the ACCEL training more than once (slightly agree 36%, agree 21%).

Participant mileage

Participants reported their miles driven each week between the two study visits. Those holding an intermediate license at the time of enrolling in the study drove significantly more miles (M = 493.30, SD = 53.60) than those with a minor school license (M = 294.40, SD = 33.83), t (90) = 3.54, p = 0.001. Additionally, those in the ACCEL (M = 329.14, SD = 279.01) condition did not vary in miles driven when compared to the control condition (M = 341.66, SD = 279.49). However, those in the PALM (M = 410.65, SD = 316.38) condition drove significantly more than those in the control condition, t (90) = 2.20, p = 0.03. Thus, the number of miles driven by participants between the two study visits was included as a covariate in all analyses.

Eye glance behavior & driving performance in hazard scenarios in relation to training condition

Mid-block crosswalk event

This event was complex in that there were multiple cues present in the scene to alert the participants to the presence of the potential hazard. These included two signs for the pedestrian crossing, the painted crosswalk across the street, and pedestrians walking on the sidewalk toward the crosswalk. Therefore, in addition to coding the start and end time of each glance, the analysts also noted the glance location (warning signs, crosswalk, and pedestrians), when a glance was made to the left side of the crosswalk, and when a glance was made to the area in front of the stopped vehicle to check for the presence of pedestrians in the crosswalk. In addition to analyzing eye measures over the entirety of the event, analysis was also completed only using glances that were made in close proximity to the event (250 feet from crosswalk). Minimum speed was the only driving performance measure considered. Results for the interaction of Condition and Visit, as well as the effect of Visit by Condition, can be found in Table 4.

When examining the event at close proximity, a significant Condition x Visit interaction emerged for number of glances when comparing those in the PALM and control conditions. When examined by condition, those in the PALM condition were predicted to have a significant, 1.10 increase in number of glances to the event at visit 2. While not significant, those in the control group showed the opposite pattern with a predicted 0.50 decrease in glances to the event.

While none of the other eye tracking measures were statistically significant for either the interaction or the effect of Visit, there were a few notable observations. Those in the PALM condition had a trend toward spending more time looking at relevant areas of the event during visit 2 (Figure 30). While the participants varied in the likelihood of scanning the left side of the crosswalk at visit 1, PALM-trained participants made slightly fewer looks to the left during visit 2 (Figure 31). Interestingly, all conditions saw an increase in the likelihood of glancing toward the pedestrian once they could see in front of the parked vehicle at visit 2 (see Figure 32). The minimum speed during visit 2 was about 2 or 3 mph lower than visit 1 for the PALM and Control groups, respectively (see Figure 33).

Table 4. Associations of eye glance and driving performance measures with experimental condition (Condition) before and after training (Visit), mid-block crosswalk event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Eye tracking measures			β *[95% Confidence Interval]*		
Time to first glance	0.41 [−0.20, 1.01]	0.31 [−0.31, 0.92]	0.07 [−0.43, 0.58]	−0.03 [−0.31, 0.25]	−0.33 [−0.75, 0.08]
Glance count	−0.09 [−1.85, 1.68]	1.46 [−0.33, 3.46]	−0.47 [−1.62, 0.68]	0.97 [−0.23, 2.14]	−0.48 [−1.92, 0.96]
Total looking time	0.09 [−2.05, 2.22]	1.88 [−0.28, 4.03]	−0.01 [−1.37, 1.35]	1.77 [−0.39, 3.93]	−0.03 [−1.87, 1.82]
Eye tracking measures – close proximity					
Glance count	0.31 [−0.99, 1.60]	**1.61** [0.30, 2.93]	−0.11 [−0.66, 0.45]	**1.10** [0.16, 2.04]	−0.50 [−1.45, 0.42]
Total glance time	−0.52 [−2.21, 1.16]	0.79 [−0.91, 2.49]	−0.17 [−1.16, 0.81]	1.07 [−0.66, 2.80]	0.37 [−1.17, 1.91]
Number of glances to the left side of crosswalk	0.06 [−0.30, 0.42]	−0.06 [−0.42, 0.31]	−0.03 [−0.30, 0.24]	−0.14 [−0.39, 0.12]	−0.09 [−0.36, 0.19]
Likelihood of glance to the pedestrian after occlusion	0.41 [−1.09, 1.91]	−0.30 [−1.81, 1.22]	0.99^{+} [−0.0004, 2.02]	0.26 [−0.77, 1.30]	0.63 [−0.46, 1.76]
Simulator measures					
Minimum speed	2.71 [−1.76, 7.18]	−1.06 [−5.53, 3.42]	0.50 [−3.45, 4.45]	−3.02 [−7.34, 1.31]	−2.25 [−6.79, 2.30]

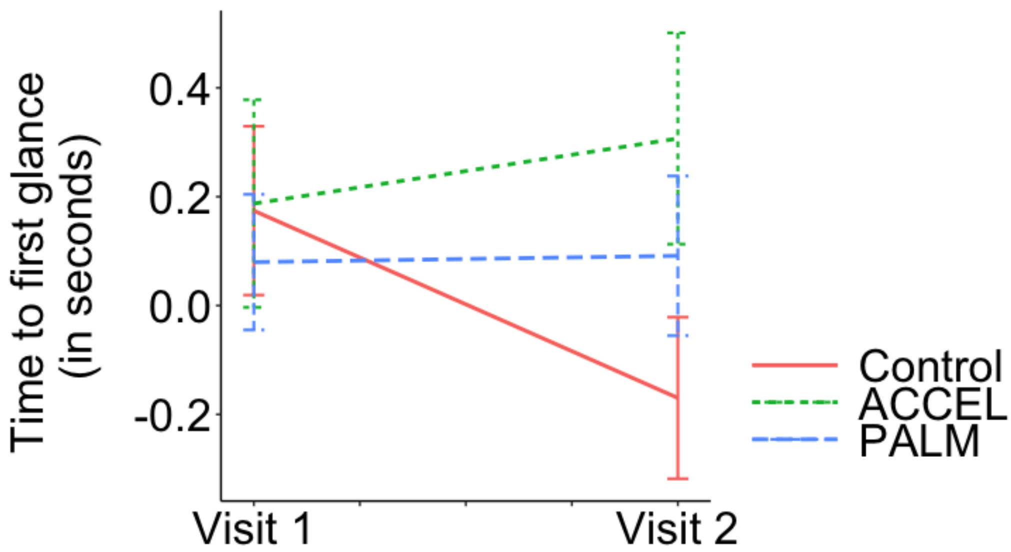

Figure 28. Time to first glance (in seconds) at the mid-block crosswalk event over the entire event window.

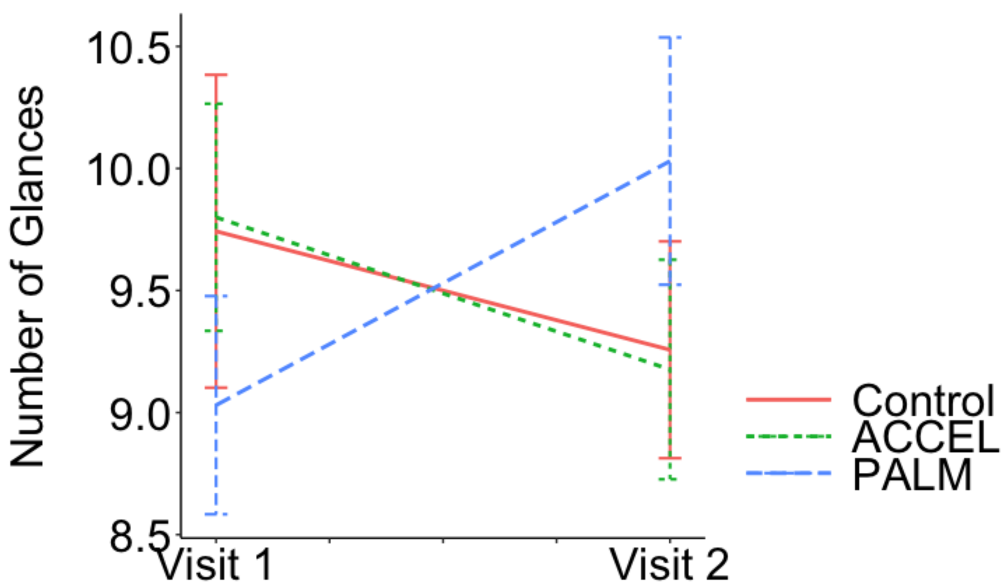

Figure 29. Total number of glances to the mid-block crosswalk event over the entire event window.

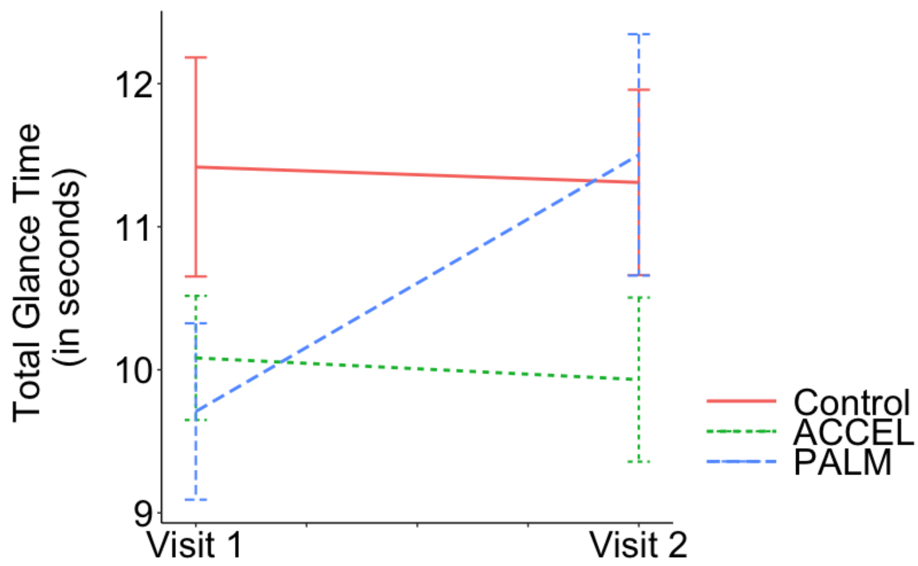

Figure 30. Total time (in seconds) spent glancing at mid-block crosswalk across the entire event window.

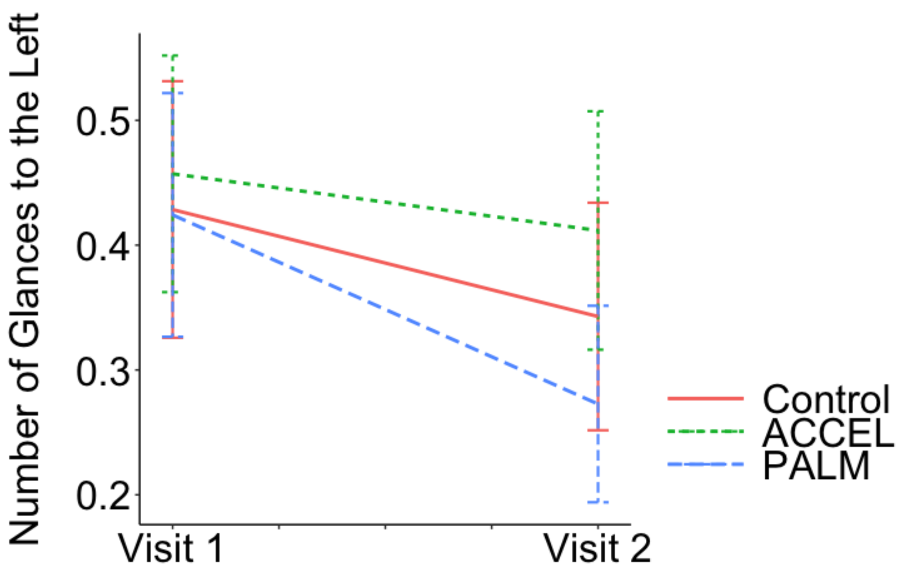

Figure 31. Number of glances toward the left side of the crosswalk.

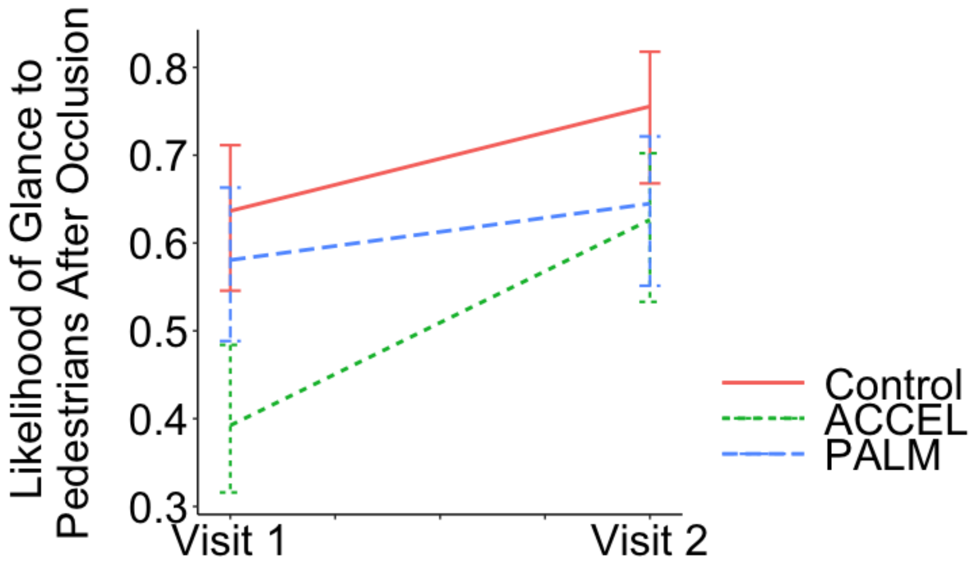

Figure 32. Probability of participants scanning for the pedestrians located in front of the stopped vehicle following occlusion for the mid-block crosswalk.

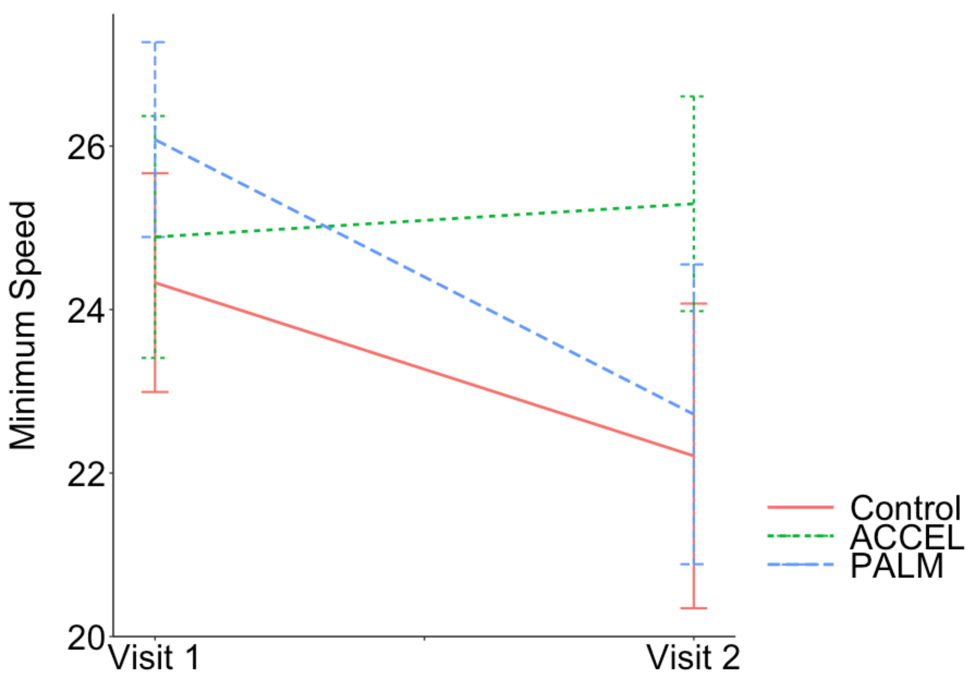

Figure 33. Minimum speed (mph) during the mid-block crosswalk.

Parallel parked car event

The eye movement dependent measures considered—time to first glance, number of glances, total glance time to the parallel parked car—were calculated for the entire event, from when the car was visible at a distance of about 700 feet. Number of glances and total looking time were also calculated for the time when the participant was in closer proximity to the car, beginning from about 300 feet away. The driving performance measures considered were whether the participant released the accelerator at any time during the entire event window and the lateral position of the participant's simulated vehicle when they passed the parked car. The results are shown in Table 5.

A number of significant effects were identified when analyzing glance data for the parallel parked car event. When examining glance counts across the entire event window, a significant Condition x Visit interaction for those in the PALM compared to the control indicated that those in the PALM condition were estimated to have a 0.87 increase in number of glances at visit 2 compared to visit 1, where those in the control condition did not vary significantly in this regard (Figure 35). Similarly, a Condition x Visit interaction for total looking time emerged when comparing the ACCEL and control conditions. When examined by condition, those in the ACCEL condition showed a significant 1.35s increase in total looking time from visit 1 to visit 2, where as those in the control condition had a predicted 0.30s decrease in total looking time (see Figure 36).

When examining the measures at close proximity to the event, significant Condition x Visit interactions emerged when comparing the ACCEL and PALM conditions to the control condition. When examined by condition, those in the ACCEL and PALM condition showed 0.23 and 0.27 increases in number of glances to the event at visit 2, respectively. Those in the control condition showed a similar change, with a 0.20 increased glance count at visit 2. However, this result was only marginally significant ($p=.07$). Finally, despite the absence of a significant Condition x Visit interaction for total glance time at close proximity, those in the PALM condition were estimated to have a significant 0.28s increase in total glance time to the event from visit 1 to visit 2.

Analysis of the driving performance dependent measures did not reveal any statistically significant Condition x Visit interactions. However, ACCEL participants were marginally less likely to release the accelerator pedal during the parallel parked car event at visit 2 (see Figure 37). Participants who completed the ACCEL training moved to the left and increased the lateral distance between them and the parallel parked car by about 1 foot in visit 2. Those in the PALM condition similarly moved to the left by about 0.6 feet, whereas those in the Control condition did not have a change in lateral position from visit 1 to visit 2 (see Figure 38).

Table 5. Associations of eye glance and driving performance measures with experimental condition (Condition) before and after training (Visit), parallel parked car event.

Measures	Condition x Visit Interaction: ACCEL vs. Control	Condition x Visit Interaction: PALM vs. Control	Effect of Visit by Condition: ACCEL	Effect of Visit by Condition: PALM	Effect of Visit by Condition: Control
	β [95% Confidence Interval]				
Eye tracking measures					
Time to first glance	−0.93 [−3.21, 1.37]	−0.06 [−2.36, 2.21]	−0.40 [−2.02, 1.22]	0.46 [−1.14, 2.06]	0.53 [−0.94, 2.04]
Glance count	1.16 [−0.11, 2.43]	1.37 [0.09, 2.64]	0.67 [−0.07, 1.47]	0.87 [0.08, 1.66]	−0.48 [−1.44, 0.52]
Total glance time	1.54 [0.24, 2.83]	1.10 [−0.19, 2.40]	1.35 [0.46, 2.29]	0.92 [−0.20, 2.03]	−0.21 [−3.35, 0.62]
Eye tracking measures – close proximity					
Glance count	0.43 [0.12, 0.74]	0.47 [0.43, 0.74]	0.23 [0.02, 0.48]	0.27 [0.06, 0.49]	−0.20 [−0.40, 0.001]
Total glance time	0.26 [−0.06, 0.58]	0.20 [−0.12, 0.52]	0.28 [0.05, 0.52]	0.22 [−0.02, 0.47]	0.02 [−0.15, 0.19]
Simulator measures					
Accelerator release	−1.60 [−3.81, 0.61]	0.62 [−1.52, 2.77]	−1.65 [−3.63, −0.15]	0.50 [−1.16, 2.30]	−0.23 [−1.51, 1.02]
Lateral position	−1.21 [−2.82, 0.39]	−0.74 [−2.34, 0.85]	−1.09 [−2.74, 0.56]	−0.58 [−1.40, 0.23]	0.16 [−1.20, 1.53]

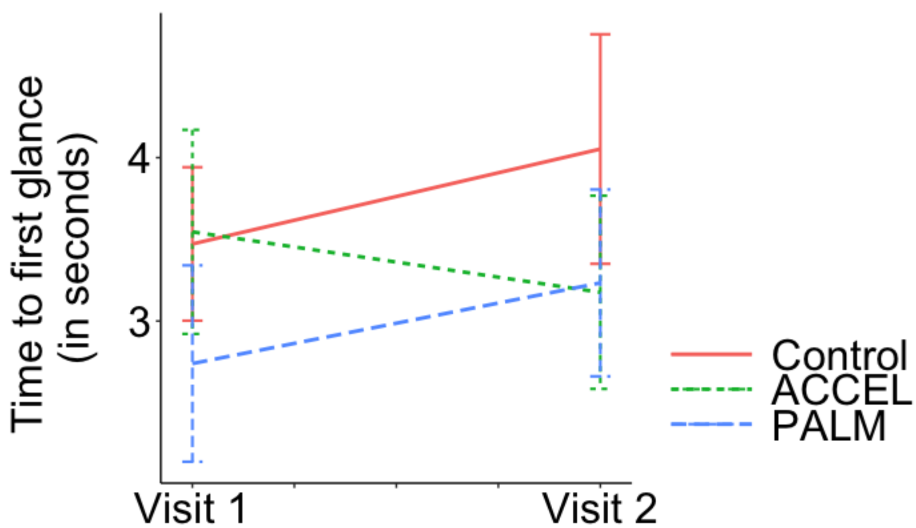

Figure 34. Time to first glance (in seconds) at the parallel parked car over entire event window.

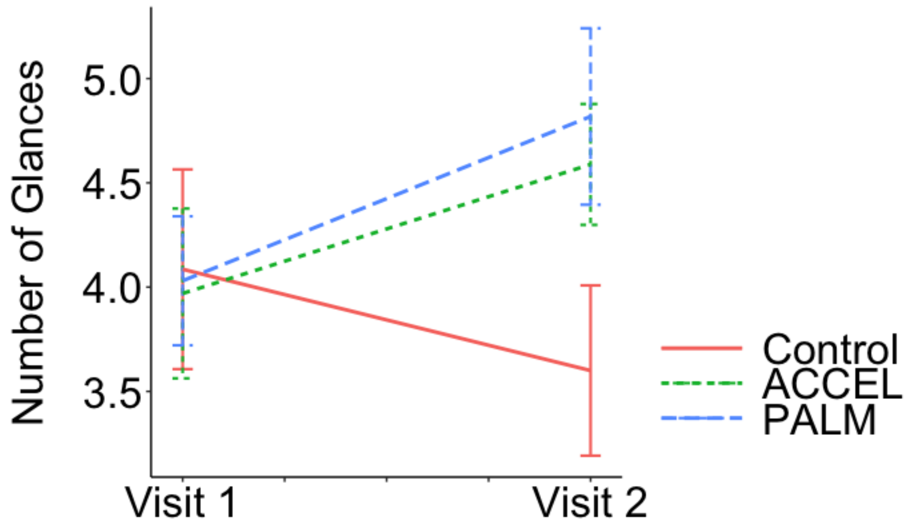

Figure 35. Number of glances to the parallel parked car over entire event window.

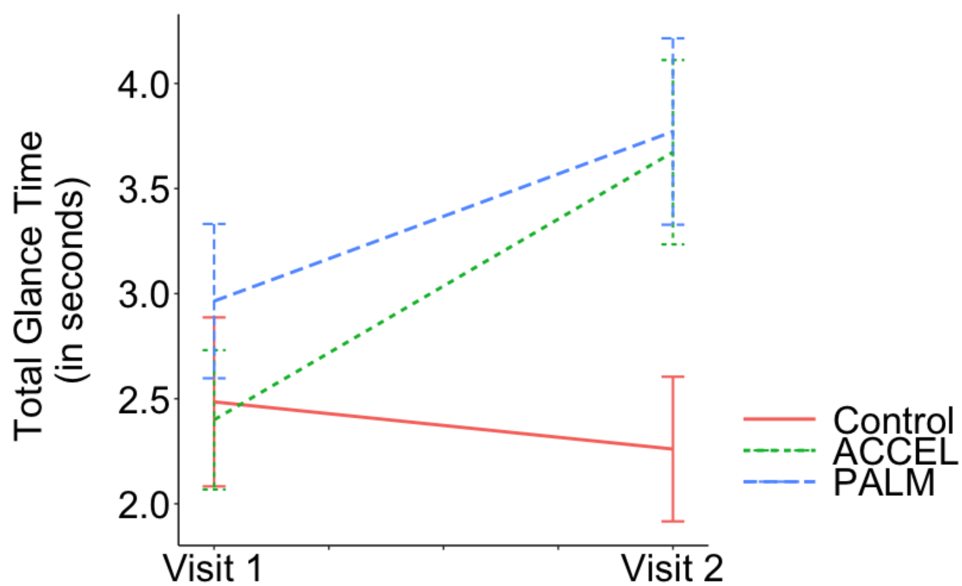

Figure 36. Total time (in seconds) spent glancing at the parallel parked car across the entire event window.

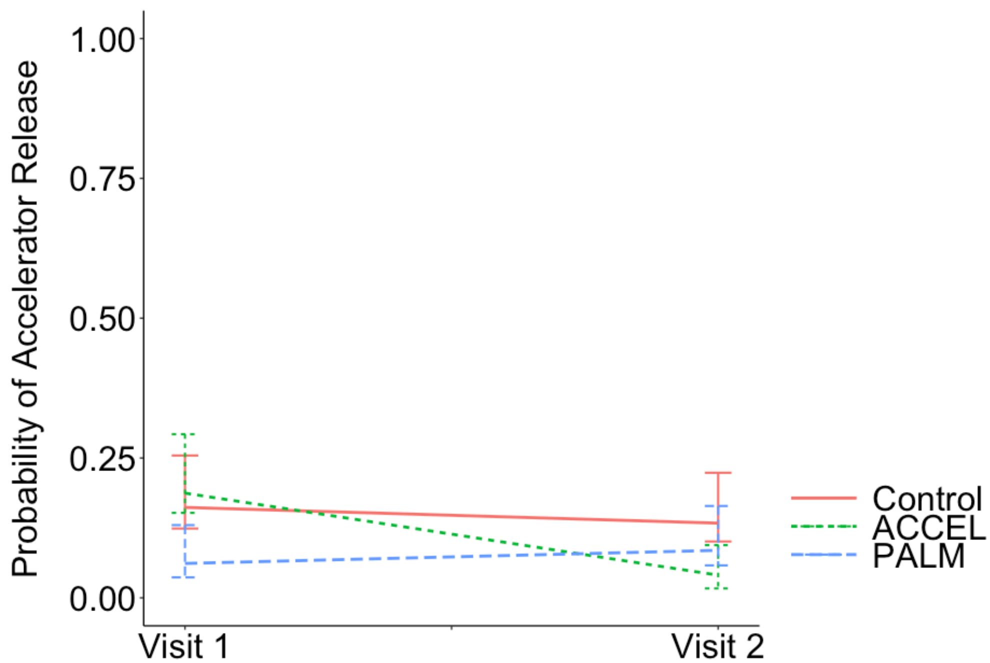

Figure 37. Probability of releasing the accelerator during the parallel parked car event across entire event window.

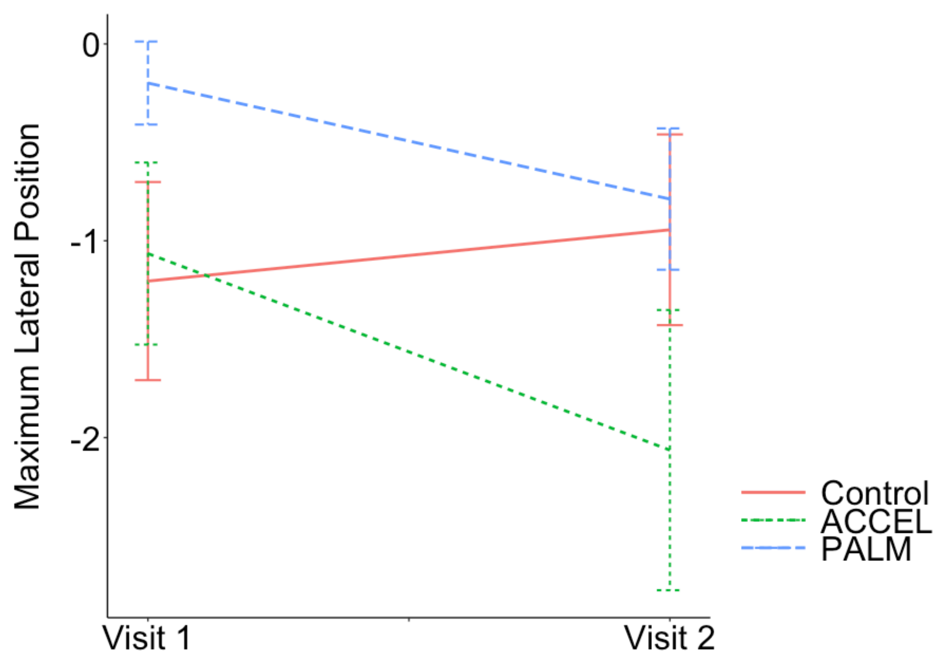

Figure 38. Lateral position (feet) when passing the parallel parked car. 0 indicates the center of the driving lane and negative values indicate lane position left of center.

Partial lane obstruction event

Given the importance of driving performance in mitigating risk when encountering a partial lane obstruction, only driving performance measures were analyzed for this event. These are accelerator release, lateral position when passing the obstructing vehicle, and distance to the obstructing vehicle when participant's left tires leave the driving lane. Table 6 shows the analytical results. While not statistically significant, those in the ACCEL condition were slightly more likely to release the accelerator at visit 2 compared to visit 1, whereas those in the control condition were slightly less likely to do so (see Figure 39). There were no differences across the training conditions in lateral position when passing the obstructed vehicle at visit 2, nor for distance to the obstructing vehicle when participants partially or fully moved out of the travel lane.

Table 6. Associations of driving performance measures with experimental condition (Condition) before and after training (Visit), partially obstructed lane event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Simulator measures	β *[95% Confidence Interval]*				
Accelerator release	1.68 [−0.05, 3.42]	0.75 [−0.94, 2.45]	0.54 [−0.58, 1.72]	−0.82 [−1.36, 0.97]	−1.05 [−2.30, 0.20]
Lateral position	0.10 [−0.89, 1.09]	−0.08 [−1.07, 0.91]	−0.20 [−1.07, 0.65]	−0.38 [−1.05, 0.28]	−0.29 [−0.89, 0.32]
Distance to obstructing vehicle	0.13 [−0.17, 0.41]	0.002 [−0.27, 0.31]	0.12 [−0.10, 0.33]	0.04 [−0.18, 0.26]	−0.02 [−0.21, 0.17]

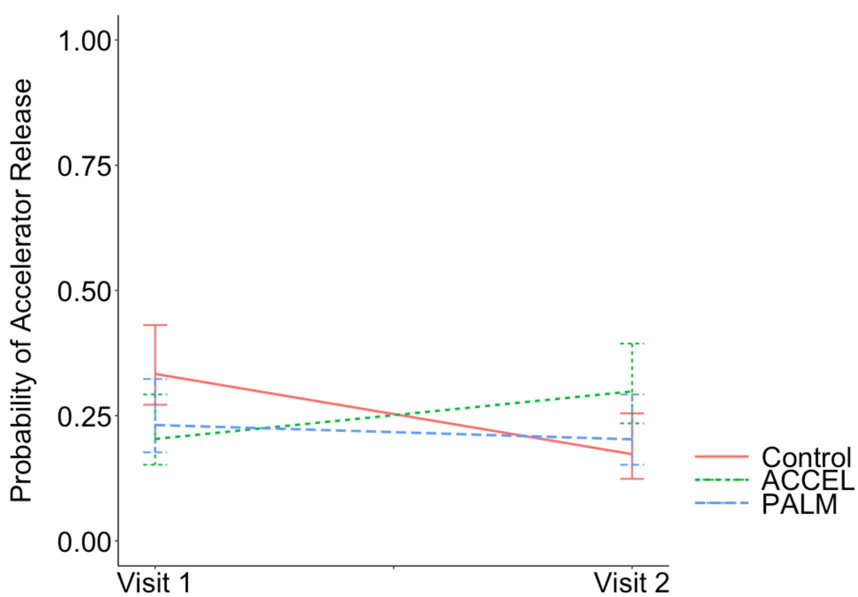

Figure 39. Probability of releasing the accelerator during the partial lane obstruction event.

Dynamic object event

The driving dependent measures analyzed for this event are accelerator release and lateral position when passing the object. The results are shown in Table 7.

While not significant, there was a pattern of participants in the ACCEL and PALM training conditions being 0.27 and 0.77, respectively, times as likely to release the accelerator at visit 2 (see Figure 40). Similar to the partial lane obstruction event, there were no differences across the training conditions in lateral position when passing the dynamic object event at visit 2 (see Figure 41). However, despite seeming high variability between the conditions at visit 1, participants seem to converge on likelihood of accelerator release at visit 2. The difference in the training conditions for lateral position at visit 1 can be attributed to two participants in the control condition who were driving in the left lane as they passed the dynamic object.

Table 7. Associations of driving performance measures with experimental condition (Condition) before and after training (Visit), dynamic object event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Simulator measures	β *[95% Confidence Interval]*				
Accelerator release	−1.32 [−2.93, 0.28]	−0.59 [−2.12, 0.95]	−1.30 [−2.60, −0.01]	−0.32 [−1.65, 1.01]	0.26 [−0.83, 1.34]
Lateral distance	−0.66 [−1.81, 0.49]	−0.57 [−1.72, 0.58]	−0.41 [−1.09, 0.27]	−0.32 [−0.99, 0.35]	0.24 [−0.76, 1.25]

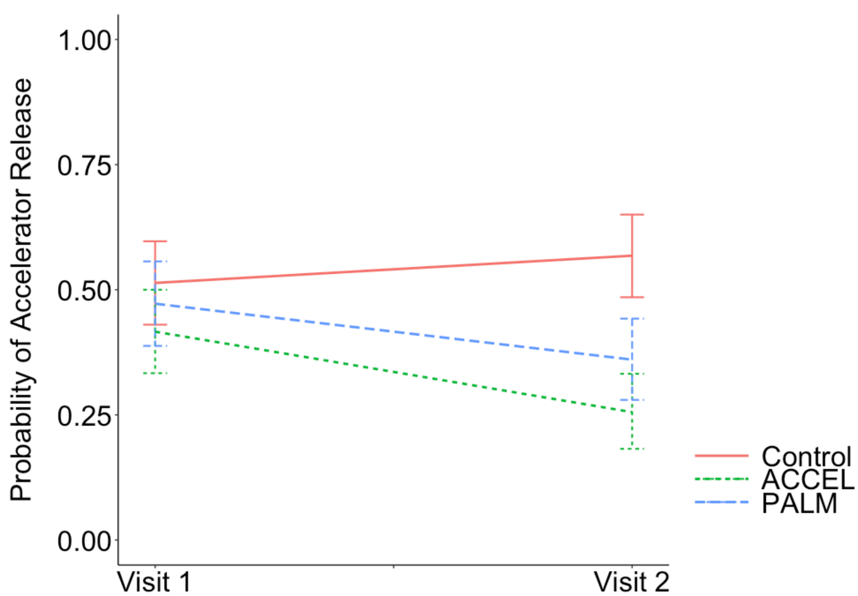

Figure 40. Probability of releasing the accelerator during the dynamic object event

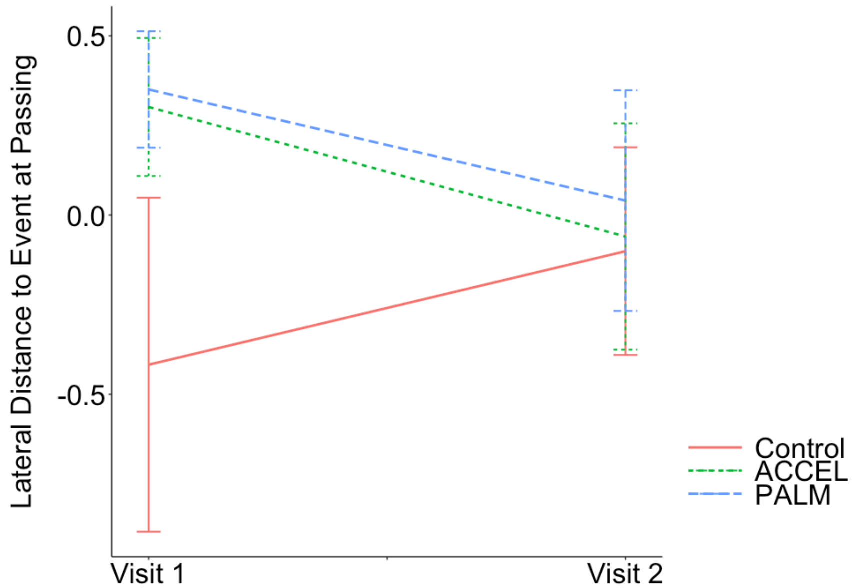

Figure 41. Lateral distance when passing the dynamic object event.

Potential incursion event

The eye measures considered for the potential incursion event included time to first glance, number of glances to the event, and total glance time. These measures were derived for the entirety of the event. Additionally, measures of number of glances and total glance time were derived for the portion of the event occurring after the vehicle began to move forward after initially stopping. The driving dependent measure analyzed for this event was accelerator release. The results are shown in Table 8.

When examining the entire event, a significant Condition x Visit interaction for time to first glance emerged when comparing those in the ACCEL and control conditions. When examined by condition, those in the ACCEL condition showed a non-significant 0.68s increase in the time to first glance, whereas those in the control condition showed a non-significant 0.51s decrease in time to first glance to the incursion vehicle. Additionally, despite a lack of significance in the Condition x Visit interaction for glance count and total looking time when comparing the ACCEL and Control conditions, participants in the ACCEL condition showed significant decreases from visit 1 to visit 2 in the number of glances to (Figure 43) and total looking time to the event (Figure 44). While not significant, those in the PALM condition showed a similar pattern of change from visit 1 to visit 2, with reductions in glance count and total looking time.

When examining glances to the event at close proximity, a similar pattern of results emerged for those in the ACCEL condition, with a marginally significant reduction in the number of glances and a significant 1.93s decrease in total looking time to the potential incursion event. Those in the control condition also showed marginally significant (−0.95s) decrease in the total time spent glancing at the event when in close proximity.

While there were no significant differences between the training and control conditions for accelerator release, there seemed to be a pattern whereby those in the ACCEL condition were 1.65 times as likely to release the accelerator at visit 2 compared to visit 1 (see Figure 45).

Table 8. Associations of eye glance and driving performance measures with experimental condition (Condition) before and after training (Visit), potential incursion event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Eye tracking measures			β *[95% Confidence Interval]*		
Time to first glance	**1.19** [0.05, 2.34]	0.48 [−0.71, 1.66]	0.68 [−0.17, 1.52]	−0.08 [−198, 0.83]	−0.51 [−1.18, 0.15]
Glance count	−0.77 [−2.17, 0.63]	0.48 [−0.97, 1.93]	**−1.50** [−2.61, −0.37]	−0.24 [−1.30, 0.84]	−0.75 [−1.65, 0.15]
Total glance time	−0.87 [−2.57, 0.85]	0.27 [−1.50, 2.04]	**−1.93** [−3.32, −0.55]	−0.75 [−2.52, 1.01]	−1.10 [−2.64, 0.07]
Eye tracking measures – close proximity					
Glance count	−0.05 [−1.28, 1.18]	1.22 [−0.05, 2.49]	−0.99⁺ [−2.01, 0.02]	0.31 [−0.55, 1.16]	−0.97 [−1.72, −0.21]
Total glance time	−0.64 [−2.01, 0.74]	.34 [−1.08, 1.77]	**−1.56** [−2.41, −0.70]	−0.60 [−1.75, 0.59]	−0.95 [−1.94, 0.04]
Simulator measures					
Accelerator release	1.27 [−0.36, 2.84]	0.24 [−1.39, 1.86]	0.51 [−0.60, 1.62]	−0.40 [−1.53, −0.72]	−1.00 [−2.15, 3.61]

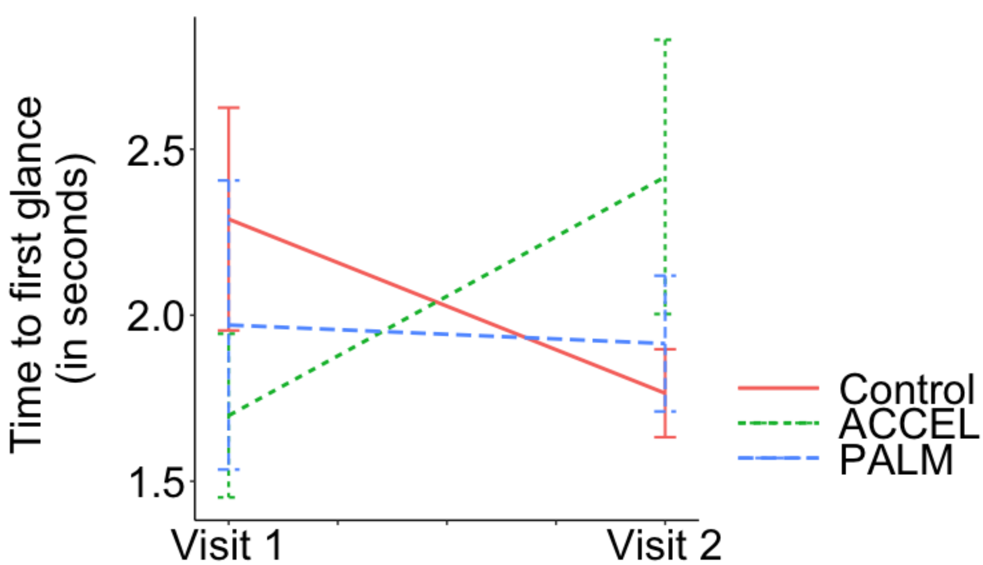

Figure 42. Time to first glance at the potential incursion vehicle over entire event window.

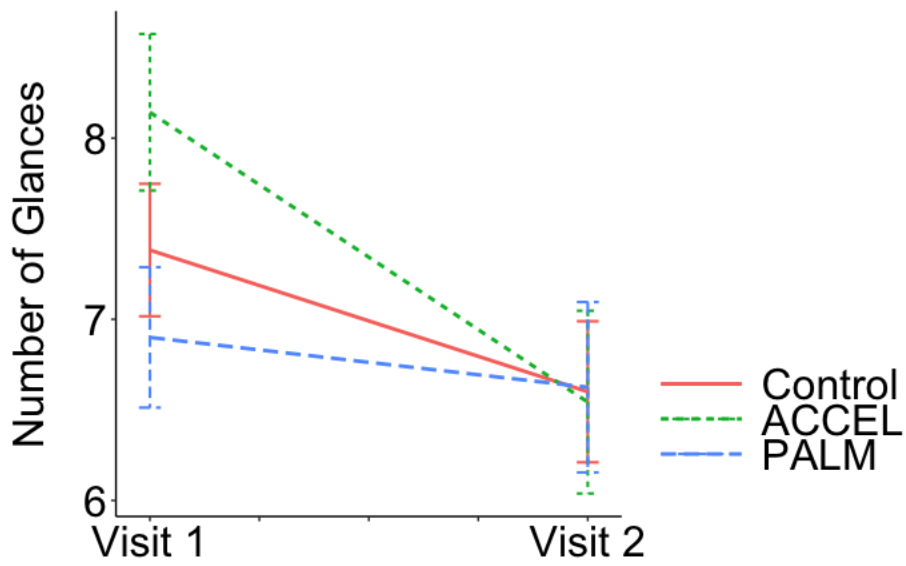

Figure 43. Number of glances to the potential incursion vehicle over entire event window.

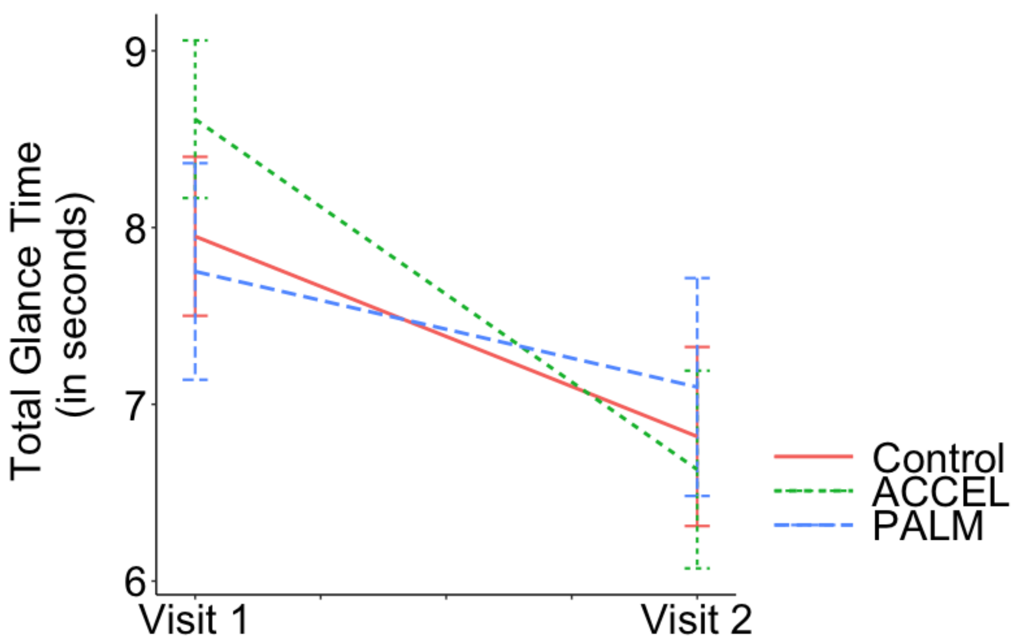

Figure 44. Total glance time to the potential incursion vehicle over the entire event window.

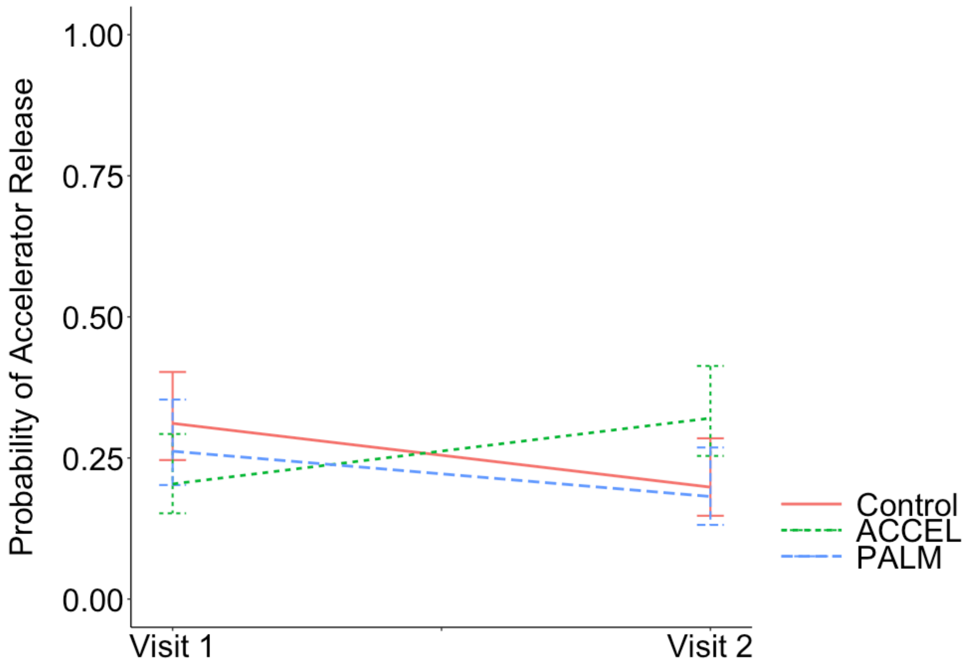

Figure 45. Probability of releasing the accelerator during the potential incursion event.

Work zone lane closure event

The driving dependent measure analyzed was (the log of) the distance from the work zone at which the participant left the lane that was closing. The results are shown in Table 9 and Figure 46. While not statistically significant, participants in the ACCEL condition changed lanes a bit sooner for the work zone; however, this amounted to an increase of only about 2 feet.

Table 9. Associations of driving performance measures with experimental condition (Condition) before and after training (Visit), work zone lane closure event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Simulator measures			β *[95% Confidence Interval]*		
Distance to event at lane change	0.24 [−0.11, 0.59]	0.12 [−0.23, 0.47]	0.21 [−0.03, 0.46]	0.07 [−0.17, 0.34]	−0.05 [−0.30, 0.19]

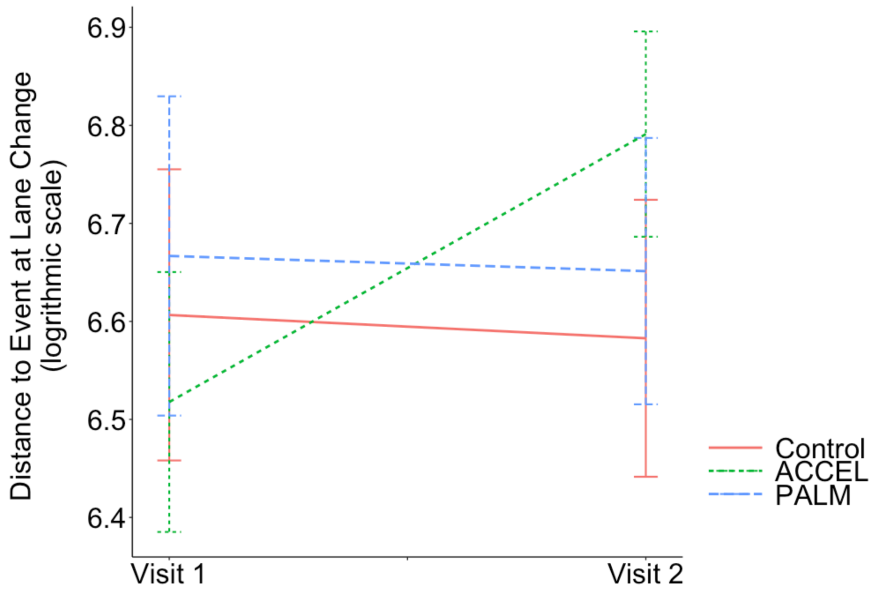

Figure 46. Distance to the work zone when leaving the closed lane.

Transition from 4-lane to 2-lane event

The driving dependent measure analyzed was (the log of) the distance from the lane merge at which the participant left the lane that was being dropped. The results are shown in Table 10. While not significant, participants in the Control condition changed lanes for the transition about 2 feet sooner at visit 2 whereas the other groups did not change between visits (Figure 47).

Table 10. Associations of driving performance measures with experimental condition (Condition) before and after training (Visit), transition from 4- lane to 2-lane event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Simulator measures			β *[95% Confidence Interval]*		
Distance to event at lane change	−0.33 [−0.69, 0.04]	−0.28 [−0.63, 0.07]	0.03 [−0.18, 0.25]	0.08 [−0.23, 0.39]	0.33 [0.13, 0.53]

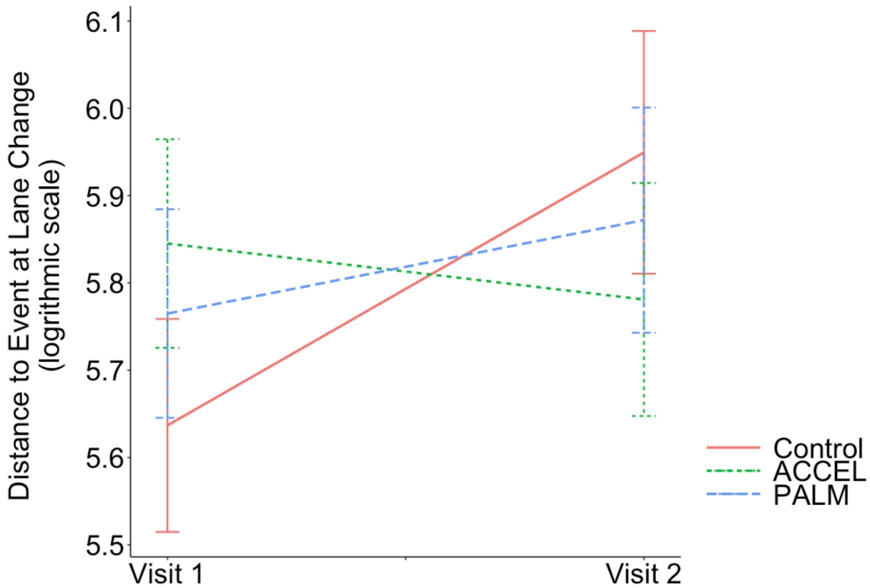

Figure 47. Distance from the end of the transition when the participant changed lanes during the 4-lane to 2-lane event.

Curve

Driving performance data for this event was summarized over two windows. The entire event window began at the first sign indicating a curve ahead and ended at the end of the curve. The second window began at the entrance of the curve and ended 45 degrees through the 90-degree curve. Driving dependent measures analyzed were maximum brake force, and rate of speed change, which was calculated by dividing the difference of the speed at the beginning and end of the window by the time duration of the window. Additionally, minimum speed was considered for the entire event window and speed when entering the curve was analyzed. Results can be found in Table 11 .

When considering the entire curve event window, there were no statistically significant results. There was a marginal reduction in maximum brake force for those in the Control condition from visit 1 to visit 2 (see Figure 48).

When considering driving performance in the curve entry, there is a significant Condition x Visit interaction for maximum brake force for those in the ACCEL condition relative to those in the Control condition. When examined by condition, significant differences in maximum brake force from visit 1 to visit 2 emerged for those in the ACCEL condition, increasing by 4.08 lbf at visit 2 (see Figure 49), a level of maximum braking similar to those in the Control condition.

Table 11. Associations of driving performance measures with experimental condition (Condition) before and after training (Visit), 90-degree curve event.

Measures	Condition x Visit Interaction		Effect of Visit by Condition		
	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Simulator measures	β *[95% Confidence Interval]*				
Entire curve event					
Minimum speed	−0.10 [−2.47, 2.26]	−0.86 [−3.28, 1.56]	0.23 [−1.57, 2.04]	−0.48 [−2.26, 1.30]	0.35 [−1.18, 1.87]
Maximum brake force	2.21 [−1.27, 5.65]	0.47 [−2.86, 3.80]	0.13 [−2.67, 2.92]	−1.24 [−4.00, 1.53]	−1.82 [−3.59, 0.08]
Speed change	−0.03 [−0.10, 0.05]	−0.02 [−0.10, 0.06]	−0.01 [−0.06, 0.05]	0.005 [−0.05, 0.04]	0.02 [−0.04, 0.08]
Entering curve					
Speed	0.55 [−2.01, 3.11]	0.26 [−2.36, 2.88]	0.62 [−1.26, 2.49]	0.41 [−1.42, 2.24]	0.07 [−1.76, 1.90]
Maximum brake force	**−0.31** [−0.35, −0.27]	3.08 [−1.36, 7.51]	**4.03** [0.43, 7.62]	2.37 [−2.54, 7.28]	0.04 [−2.68, 2.77]
Rate of speed change	−0.07 [−0.29, 0.14]	−0.05 [−0.27, 0.17]	−0.09 [−0.24, 0.06]	−0.06 [−0.23, 0.10]	−0.01 [−0.15, 0.13]

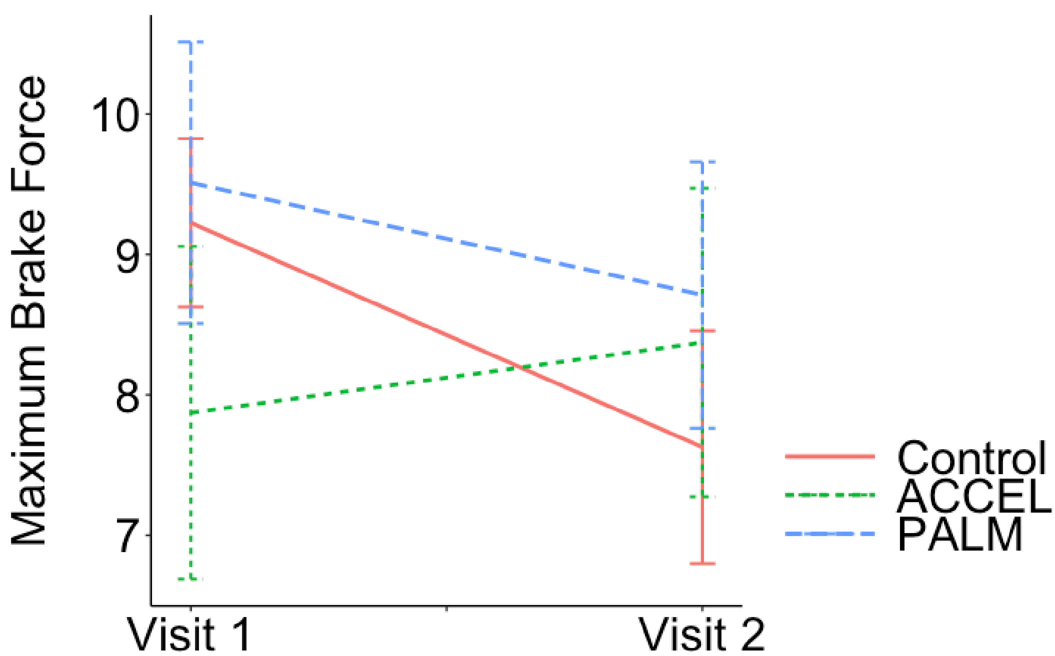

Figure 48. Maximum brake force during the entire curve event.

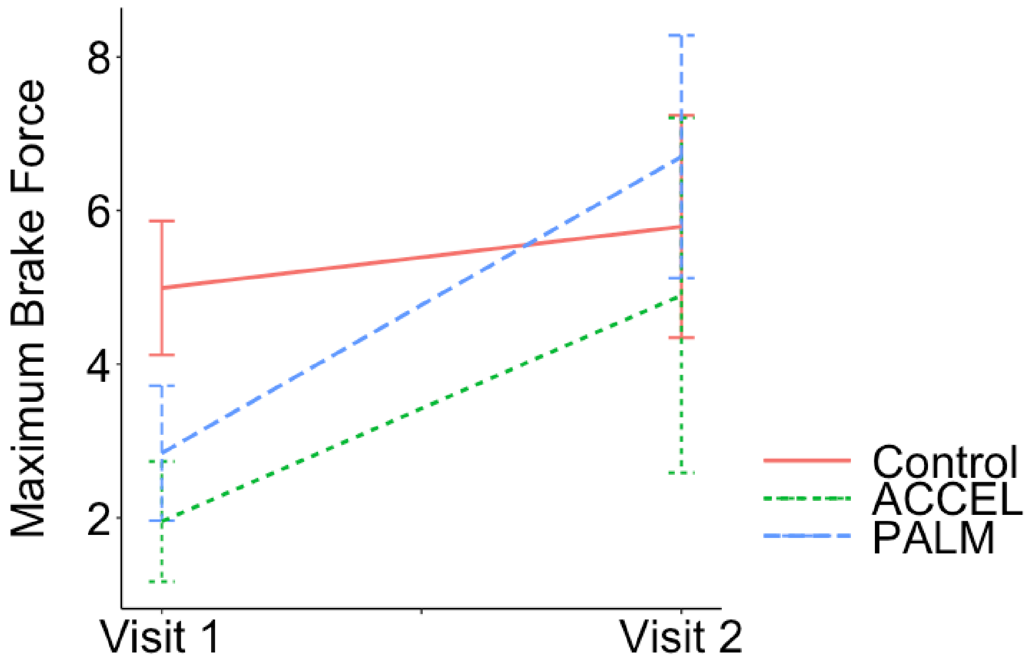

Figure 49. Maximum brake force at beginning of curve.

Platoon braking event

Like the mid-block crosswalk, this event was complex in that there were multiple areas that required monitoring throughout the event. These included the two braking vehicles in the adjacent lane, the lead vehicle in the participant's lane, and the trailing vehicle in the adjacent lane. Therefore, in addition to coding the start and end time of each glance, the analysts also noted the glance location. Also, the glances were classified according to the time sequence of the event, i.e., whether they occurred before the first braking event, after the first braking event, or after the second braking event. The dependent driving measure analyzed was accelerator release. Beta estimates and confidence intervals are shown and descriptive information about the areas monitored throughout the event are in Table 12.

Analysis of eye movements did not reveal significant differences when comparing the two training groups to the control condition when examining the entire event, the interval between the first and second braking sequence, or after the second braking sequence. When examining the entire event window, participants showed very little change in time to first glance from visit 1 to visit 2 (Figure 50). Interestingly, those in the ACCEL condition had roughly one less glance at visit 2 than at visit 1 when examining the entire event (see Figure 51), and after the first braking sequence. As for total looking time, participants showed little to no change from visit 1 to visit 2 (see Figure 52) across the entire event. And while not significant, those in the ACCEL condition increased their looking time after the second braking sequence by 0.47s at visit 2.

For accelerator release, though not statistically significant, those in the ACCEL and PALM conditions were both 0.54 times as likely to release the accelerator at visit 2, whereas those in the control condition were 1.38 times as likely to do so (see Figure 53).

Table 12. Associations of eye glance and driving performance measures with experimental condition (Condition) before and after training (Visit), platoon braking event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Eye tracking measures	β *[95% Confidence Interval]*				
Time to first glance	0.07 [−0.49, 0.63]	−0.50 [−1.07, 0.07]	0.25 [−0.80, 0.07]	−0.36 [−0.11, 0.62]	0.13 [−0.22, 0.49]
Glance count	−1.80 [−4.61, 1.00]	−0.96 [−3.81, 2.34]	−1.15 [−1.18, 0.43]	−0.26 [−2.64, 2.13]	0.61 [−1.24, 2.56]
Total looking time	−0.11 [−1.24, 1.01]	−0.15 [−1.76, 1.47]	0.15 [−0.08, 1.34]	−0.25 [−1.24, 0.73]	−0.09 [−1.30, 1.10]
Eye tracking measures – after 1st braking event					
Glance count	−0.43 [−2.02, 1.15]	0.18 [−1.43, 1.79]	−1.10 [−2.01, −0.58]	−0.45 [−1.64, 0.74]	−0.69 [−1.80, 0.43]
Total looking time	0.01 [−0.83, 0.85]	−0.07 [−0.92, 0.79]	−0.29 [−1.04, 0.35]	−0.38 [−0.92, 0.16]	−0.30 [−0.91, 0.31]
Eye tracking measures – after 2nd braking event					
Glance count	−0.81 [−2.52, 0.90]	−1.06 [−2.81, 0.67]	0.39 [−0.54, 1.31]	0.11 [−1.11, 1.33]	1.12 [−0.21, 2.46]
Total looking time	0.31 [−0.53, 1.16]	−0.34 [−0.19, 0.52]	0.47 [−0.22, 1.14]	−0.19 [−0.82, 0.48]	0.13 [−0.60, 0.85]
Simulator measures					
Accelerator release	−0.76 [−2.35, 0.83]	−0.94 [−2.86, 0.98]	−0.61 [−1.97, 0.75]	−0.62 [−2.18, 0.94]	0.32 [−0.78, 1.43]

Table 13. Means (and standard deviations) of the number of looks to the braking, leading, and trailing vehicle(s).

	Entire event					
	Visit 1			Visit 2		
	Braking vehicle	Leading Vehicle	Trailing vehicle	Braking vehicle	Leading Vehicle	Trailing vehicle
Condition						
ACCEL	4.54 (2.21)	8.14 (2.71)	1.80 (1.16)	3.47 (2.99)	6.89 (2.34)	1.57 (1.48)
PALM	5.42 (2.39)	7.76 (2.88)	2.09 (1.77)	5.30 (3.33)	7.55 (3.01)	1.91 (1.76)
Control	5.17 (2.22)	8.17 (3.33)	1.60 (1.31)	5.54 (2.80)	8.14 (3.01)	1.83 (1.79)
	After initial braking event					
	Visit 1			Visit 2		
	Braking vehicle	Leading Vehicle	Trailing vehicle	Braking vehicle	Leading Vehicle	Trailing vehicle
Condition						
ACCEL	2.03 (1.32)	3.06 (1.45)	0.69 (0.68)	1.66 (1.47)	2.54 (1.17)	0.43 (0.61)
PALM	1.97 (1.49)	2.91 (1.61)	0.76 (0.87)	1.91 (1.18)	2.16 (1.32)	0.52 (0.80)
Control	1.89 (1.32)	3.11 (1.60)	0.57 (0.81)	1.77 (1.29)	2.66 (1.63)	0.43 (0.70)
	After second braking event					
	Visit 1			Visit 2		
	Braking vehicle	Leading Vehicle	Trailing vehicle	Braking vehicle	Leading Vehicle	Trailing vehicle
Condition						
ACCEL	1.74 (1.01)	3.40 (1.50)	0.57 (0.70)	2.43 (1.48)	2.83 (1.29)	0.83 (1.04)
PALM	2.33 (1.27)	3.09 (1.35)	0.88 (1.02)	2.52 (1.73)	3.18 (1.88)	0.76 (0.83)
Control	2.23 (1.24)	3.20 (1.94)	0.71 (0.71)	2.69 (1.47)	3.77 (1.48)	0.83 (1.04)

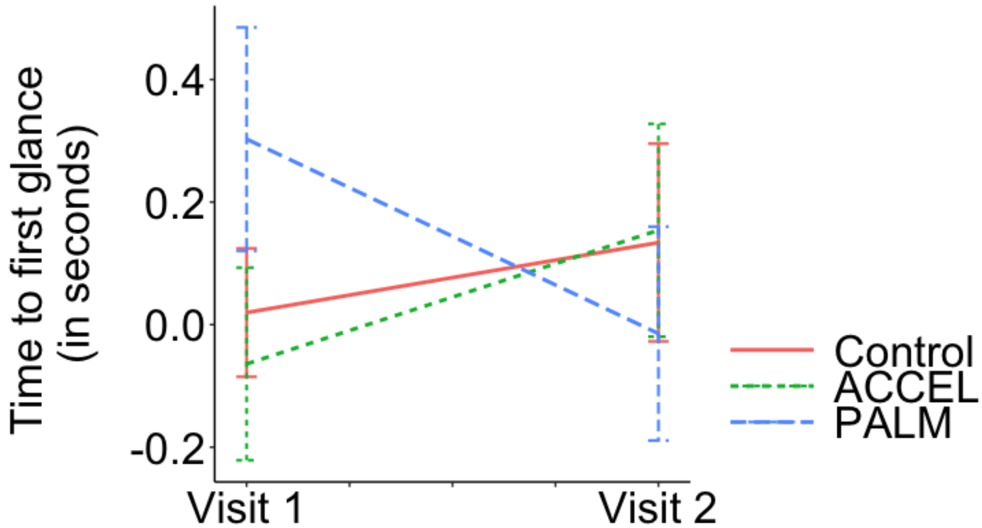

Figure 50. Time to first glance (in seconds) at the platoon event.
Note: Negative values indicate that participants were glancing to event targets prior to our defined event window.

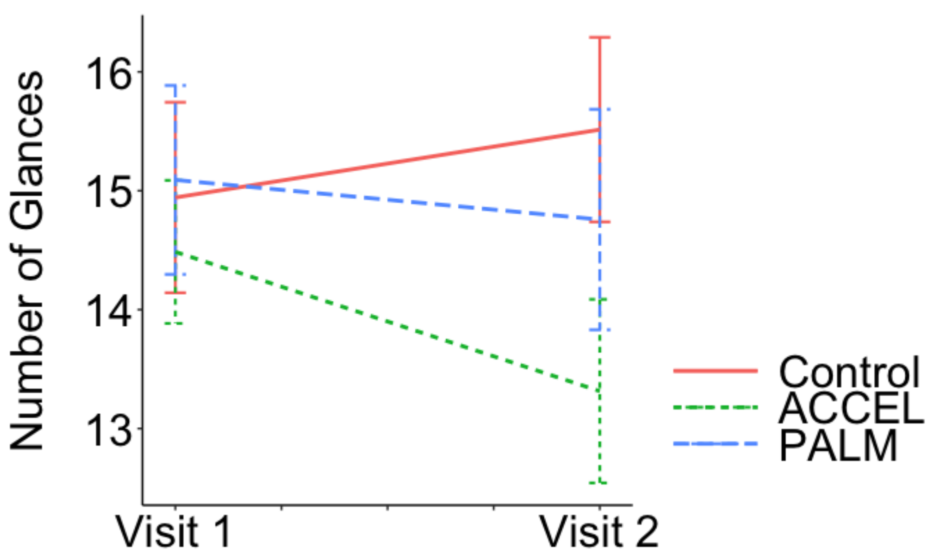

Figure 51. Number of glances to the platoon event.

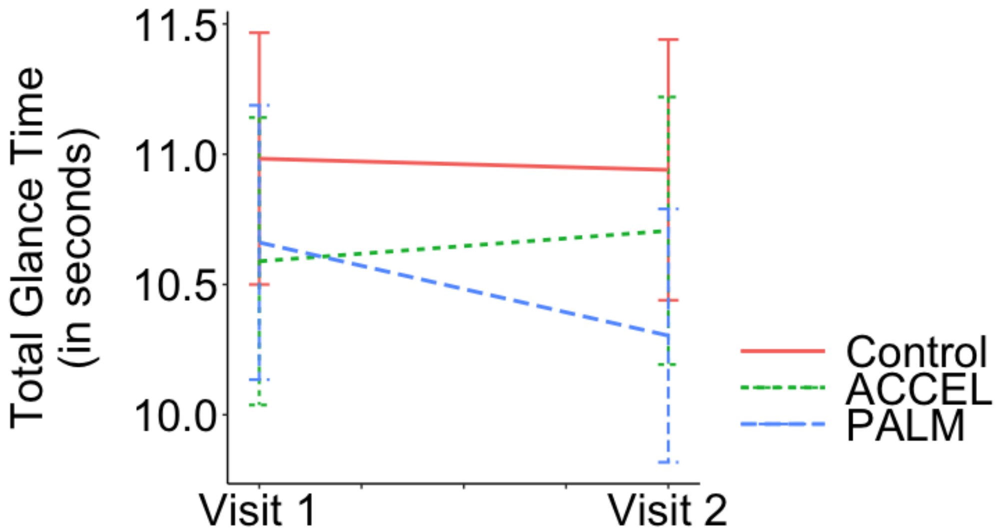

Figure 52. Total time (in seconds) spent glancing at the platoon event.

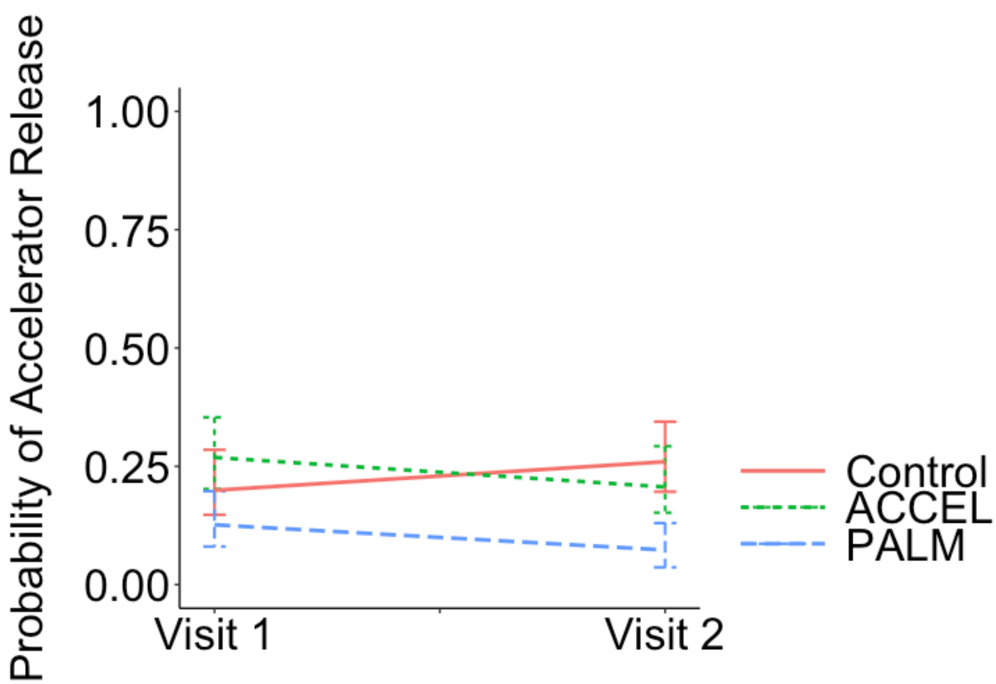

Figure 53. Probability of releasing the accelerator during the platoon event.

Obscured cross-traffic lane

The eye glance measures considered in the obscured cross-traffic lane included time to first glance, glance count, and total looking time across the entire event window. As with other events, measures of glance count and total looking time were also analyzed when in close proximity to the event, about 150 feet from the center of the intersection. Beta estimates and confidence intervals can be found in Table 14.

Again, there were no significant effects of condition, visit, or their interaction detected for the obscured cross-traffic lane either across the entire event window or at close proximity. All conditions showed very little change in the time it took the participants to glance to the event (Figure 54) or time spent looking at the event (Figure 56).

Table 14. Associations of eye glance and driving performance measures with experimental condition (Condition) before and after training (Visit), obscured cross-traffic lane event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Eye tracking measures			β [95% Confidence Interval]		
Time to first glance	−0.12 [−1.09, 0.85]	0.04 [−0.90, 1.02]	0.06 [−0.56, 0.68]	0.17 [−0.49, 0.84]	0.16 [−0.52, 0.85]
Glance count	−0.19 [−0.74, 0.36]	−0.49 [−1.04, 0.07]	0.07 [−0.31, 0.44]	−0.26 [−0.66, 0.15]	0.23 [−0.17, 0.64]
Total looking time	−0.03 [−0.29, 0.25]	−0.09 [−0.23, 0.16]	0.05 [−0.16, 0.25]	−0.02 [−0.18, 0.14]	0.07 [−0.15, 0.27]
Eye tracking measures – close proximity					
Glance count	−0.12 [−0.49, 0.25]	−0.18 [−0.55, 0.19]	0.03 [−0.28, 0.33]	−0.04 [−0.29, 0.21]	0.14 [−0.06, 0.36]
Total looking time	0.03 [−0.14, 0.21]	−0.0002 [−0.18, 0.18]	0.07 [−0.07, 0.22]	0.04 [−0.08, 0.15]	0.04 [−0.06, 0.13]

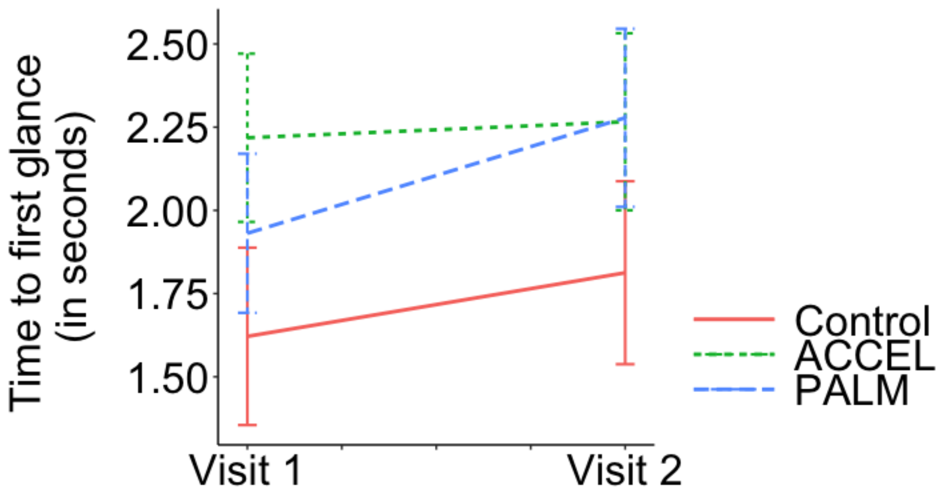

Figure 54. Time to first glance (in seconds) spent glancing at the obscured cross lane across the entire event.

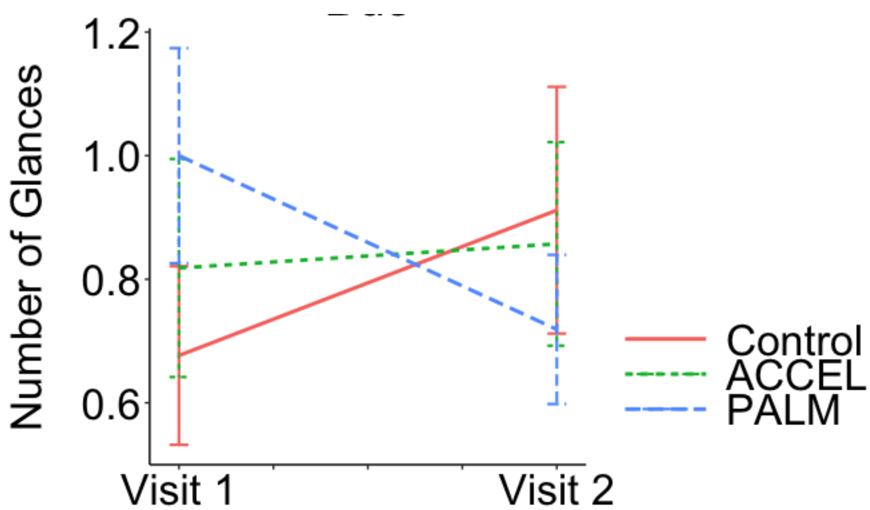

Figure 55. Number of glances to the obscured cross-traffic lane across the entire event.

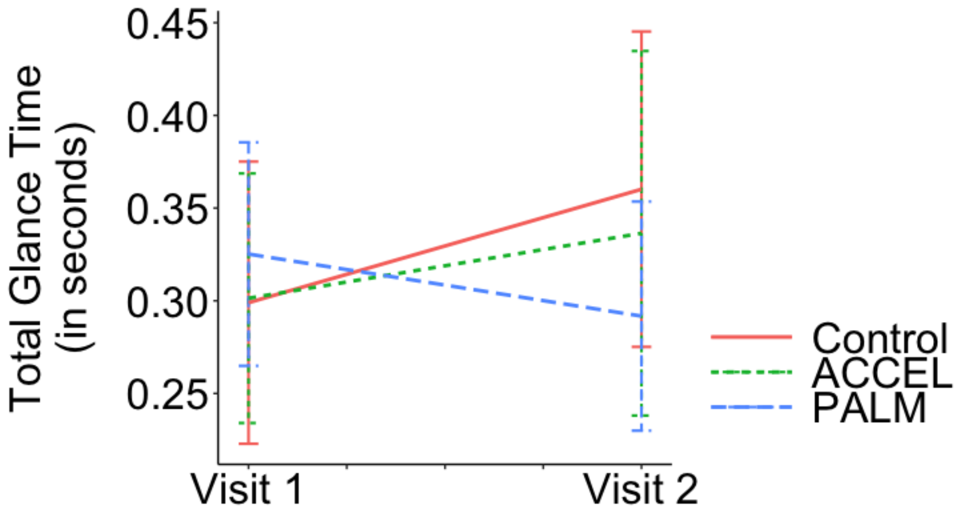

Figure 56. Total time (in seconds) spent looking at the obscured cross-traffic lane across the entire event window.

Obscured T-intersection

The eye movement dependent measures considered—time to first glance, number of glances, and total looking time to either the intersection warning sign or the intersection itself—were calculated for the entire event, beginning approximately 500 feet before the sign. Number of glances and total looking time were also calculated for the interval when the participant was in closer proximity to the intersection, beginning about 215 feet before the intersection. In addition to coding the beginning and end of each glance, coders also noted the location of each glance as being either to the sign or the intersection. Beta estimates and confidence intervals can be found in Table 15.

As with other events, there was a lack of significant findings when analyzing the obstructed T-intersection. Those in the PALM and control conditions showed the most change from visit 1 to visit 2. When examining the entire event window, those in the PALM condition reduced the time to make their first glance to the event by 0.57s (Figure 57), reduced the number of glances made to the event by 0.68 (Figure 58), and reduced the overall time spend glancing to the event (Figure 59) by 0.39s. Those in control condition did not show much change in time to first glance, but like those in the PALM condition, reduced the number of glances to the event by 0.69 and reduced the overall amount of time spent looking at the event by 0.69s. Conversely, those in the ACCEL condition showed little to no change in time to first glance and number of glances to the event, but increased total looking time by 0.30s.

When examining glances to the sign and intersection separately, those in the PALM condition showed marginally significant change in total glance time of −0.35s from visit 1 to visit 2. Those in the control condition predicted a significant 0.44s reduction in total looking time. No significant results emerged when examining glances to the intersection only.

Table 15. Associations of eye glance measures with experimental condition (Condition) before and after training (Visit), obstructed T-intersection event.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Eye tracking measures			β *[95% Confidence Interval]*		
Sign and T-intersection					
Time to first glance	0.23 [−2.54, 2.08]	−0.78 [−3.10, 1.54]	0.01 [−1.72, 1.70]	−0.57 [−2.19, 1.04]	0.01 [−1.32, 1.33]
Glance count	0.66 [−1.11, 2.44]	0.06 [−1.75, 1.88]	−0.001 [−1.19, 1.28]	−0.68 [−1.81, 0.45]	−0.69 [−2.09, 0.69]
Total glance time	0.99 [−0.06, 2.04]	0.32 [−0.75, 1.40]	0.30 [−0.27, 0.87]	−0.39 [−1.17, 0.40]	−0.69 [−1.52, 0.12]
Sign only					
Glance count	0.10 [−0.85, 1.03]	0.10 [−0.84, 1.02]	−0.18 [−0.82, 0.47]	−0.26 [−0.81, 0.29]	−0.48 [−1.06, 0.19]
Total glance time	0.19 [−0.30, 0.68]	0.03 [−0.46, 0.52]	−0.15 [−0.40, 0.12]	-0.35^{+} [−0.69, −0.004]	**−0.44** [−0.76, −0.09]
Intersection Only					
Glance count	0.43 [−1.02, 1.87]	−0.47 [−1.93, 1.00]	0.32 [−0.66, 1.31]	−0.79 [−1.67, 0.08]	−0.22 [−1.41, 0.96]
Total glance time	0.86 [−0.04,1.75]	0.17 [0.74, 1.08]	0.51^{+} [.004, 1.02]	−0.26 [−0.89, 0.38]	−0.37 [−1.14, 0.38]
Eye tracking measures – close proximity					
Glance count	−0.05 [−0.45, 0.37]	−0.19 [−0.61, 0.22]	−0.02 [−0.38, 0.33]	−0.20 [−0.43, 0.03]	0.01 [−0.24, 0.25]
Total glance time	0.10 [−1.47, 0.36]	0.04 [−2.21, 0.29]	0.08 [−0.05, 0.20]	−0.01 [−0.22, 0.20]	−0.04 [−0.23, 0.14]

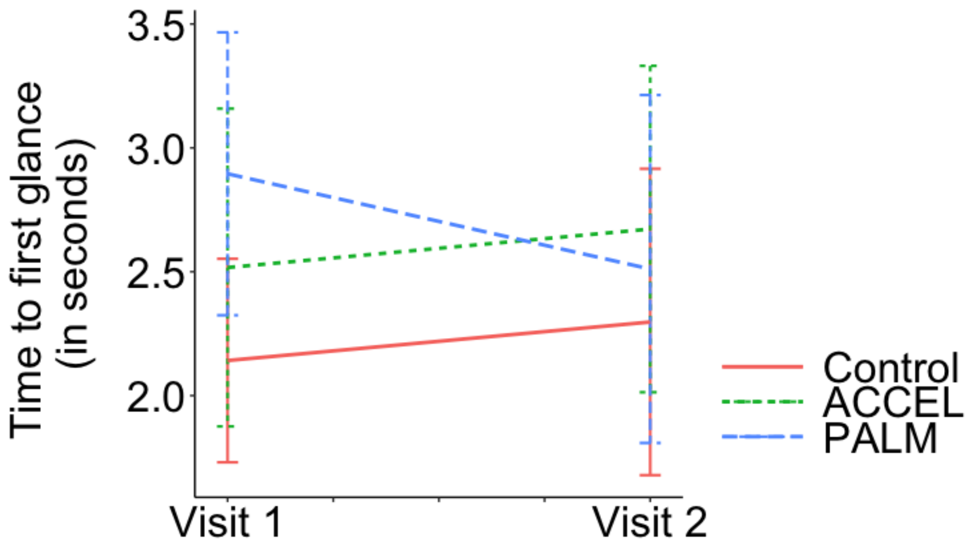

Figure 57. Time to first glance to the sign and obstructed T-intersection over entire event window.

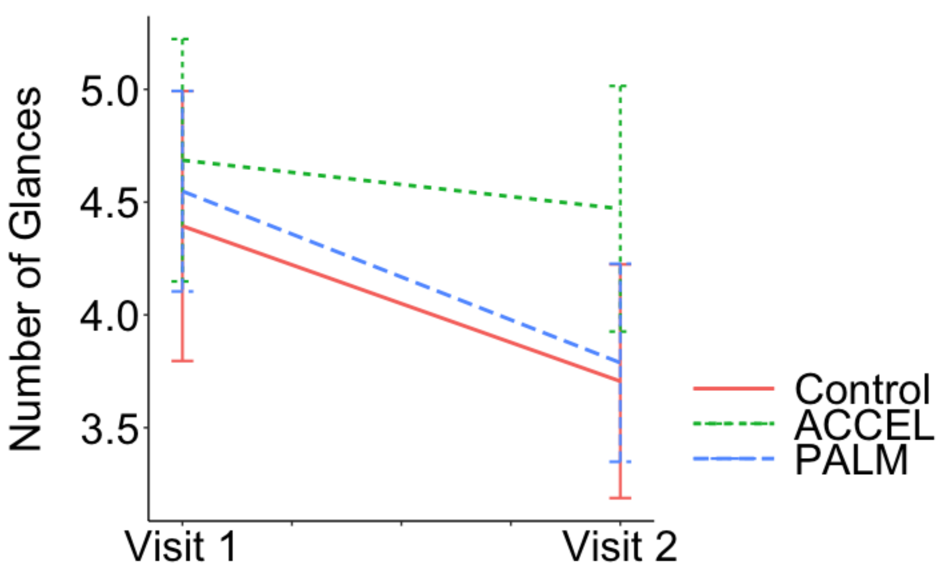

Figure 58. Number of glances to sign and obstructed T-intersection over entire event window.

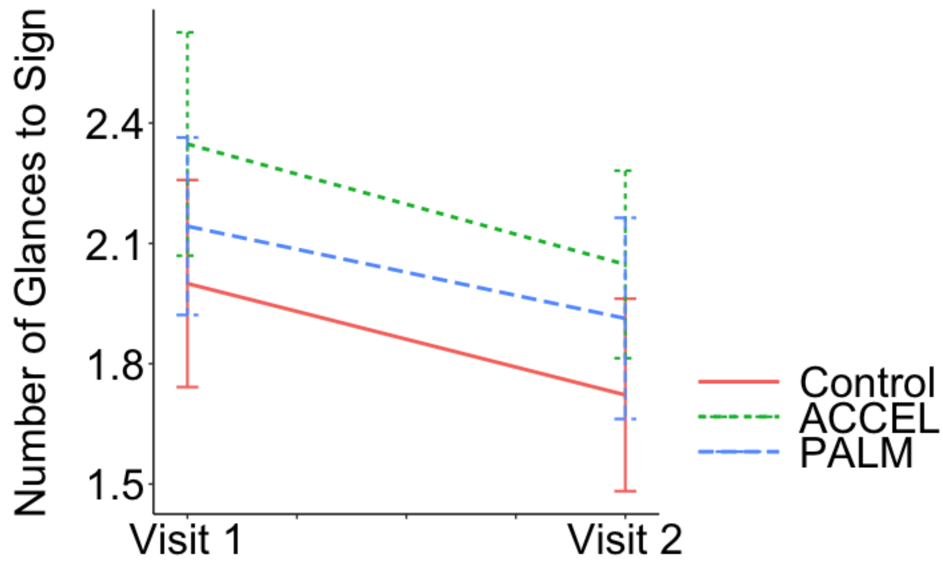

Figure 59. Number of glances to sign over entire event window.

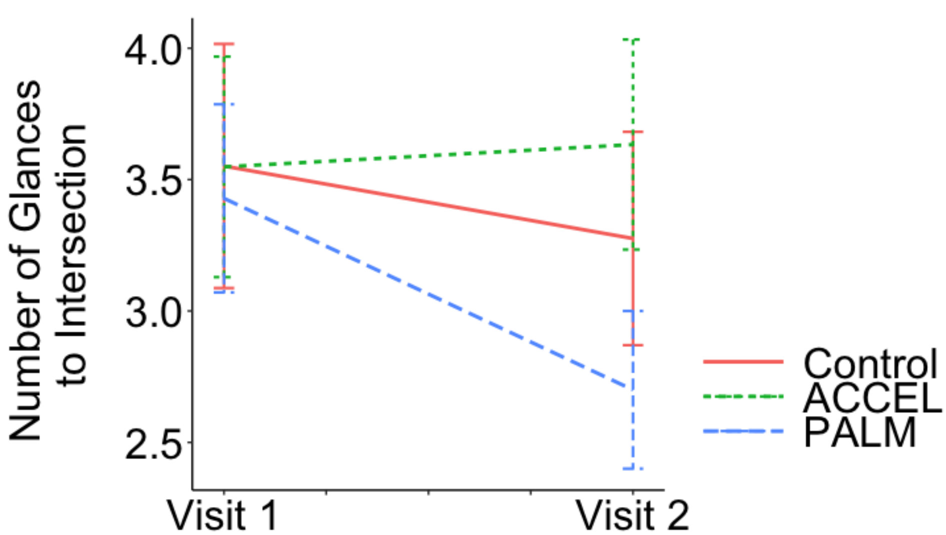

Figure 60. Number of glances to obstructed T-intersection over entire event window.

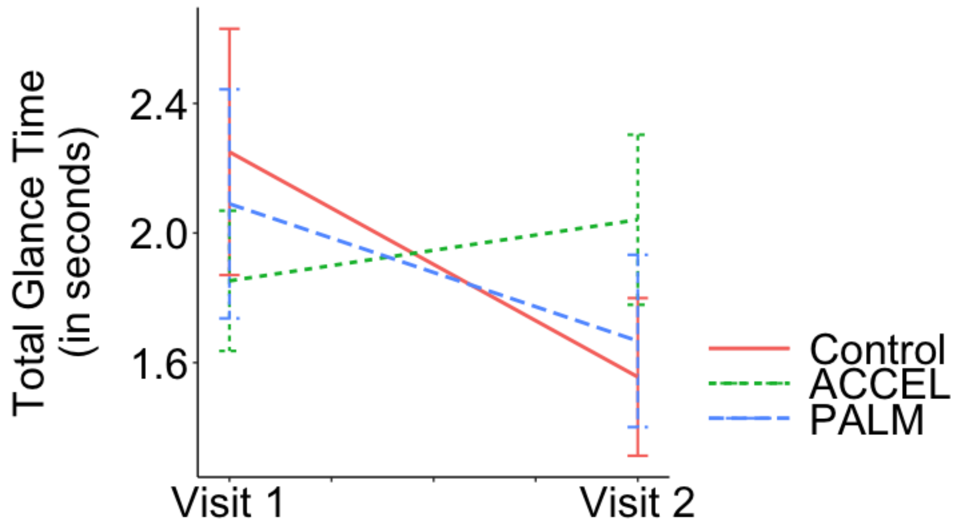

Figure 61. Total time (in seconds) spent glancing to the sign and obstructed T-intersection over the entire event window.

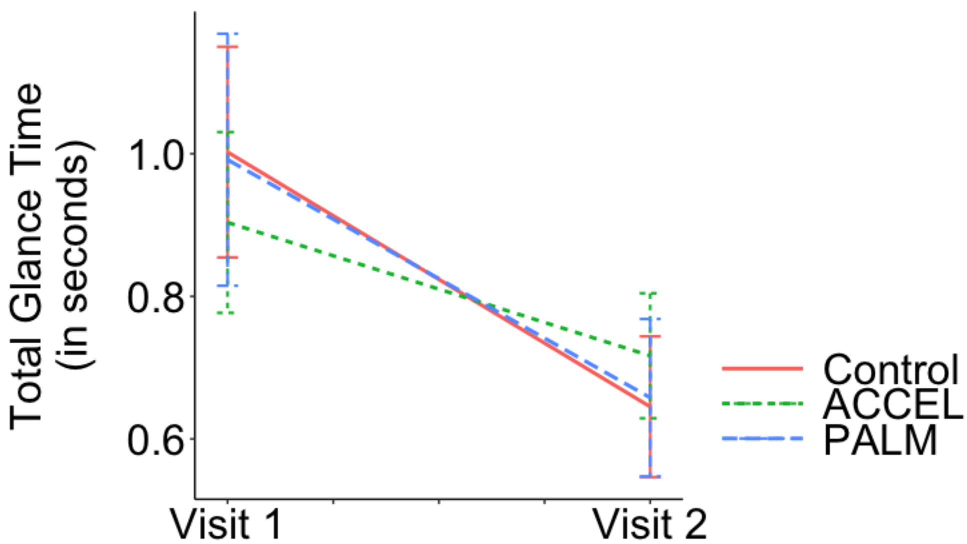

Figure 62. Total time (in seconds) spent glancing at sign over the entire event window.

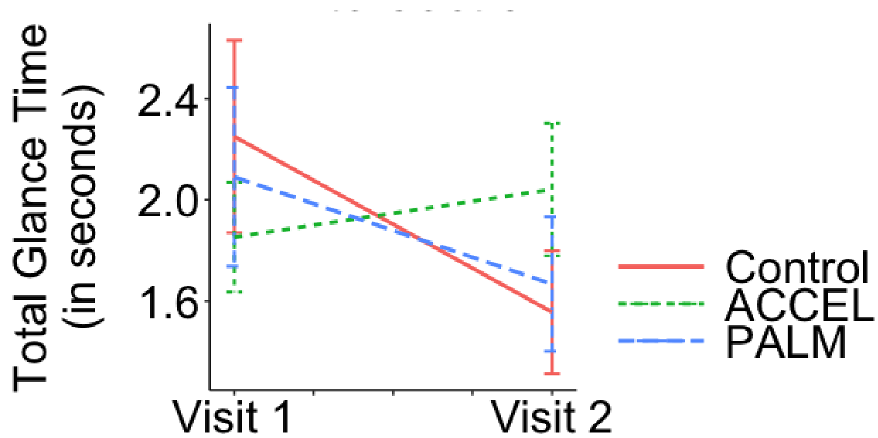

Figure 63. Total time (in seconds) spent glancing at obscured T-intersection over the entire event window.

Secondary tasks events

Secondary tasks were included in the study for the primary purpose of assessing driver glance behavior. Eye glance measures included a count of glances to the task over two seconds and the proportion of glances over 2 seconds. Of the glances that were over 2 seconds, the average duration of glance time was 3.51s (SD = 1.53), 3.63s (1.55), and 3.65s (1.69), for those in the ACCEL, PALM, and control, respectively. Driving performance measures of standard deviation of speed and standard deviation of lane position were analyzed as surrogate measures to assess how well the participants divided their attention between the secondary task and the driving task. Beta estimates and confidence intervals can be found in Table 16.

While the Condition x Visit interactions did not reach significance, there were significant visit differences for those in the ACCEL and control conditions. More specifically, Visit predicted a 0.76 and 0.58 reduction in the number of glances made to the in-vehicle task at visit 2 for those in the ACCEL and control conditions, respectively (Figure 64).

While standard deviation of speed did not yield significant results of Condition x Visit, those in the PALM condition exhibited significantly less variability in speed during the rural dialing task at visit 2 (see Figure 66). Similarly, those in the PALM condition displayed significantly less variability in lane position during the urban dialing and rural contact search task at visit 2.

Table 16. Associations of eye glance and driving performance measures with experimental condition (Condition) before and after training (Visit), secondary task events.

	Condition x Visit Interaction		Effect of Visit by Condition		
Measures	ACCEL vs. Control	PALM vs. Control	ACCEL	PALM	Control
Eye tracking measures			β *[95% Confidence Interval]*		
Glance count (over 2s)	−0.19 [−1.02, 0.64]	0.42 [−0.42, 1.26]	**−0.76** [−1.34, −0.19]	−0.15 [−0.84, 0.53]	**−0.58** [−1.12, −0.03]
Proportion of Glances (over 2s)	0.15 [−0.48, 0.78]	0.34 [−0.30, 0.98]	0.01 [−0.42, 0.44]	0.21 [−0.24, 0.66]	−0.14 [−0.60, 0.31]
Simulator measures					
Standard deviation of speed					
Contact search urban	0.18 [−0.26, 0.63]	0.08 [−0.37, 0.53]	−0.07 [−0.44, 0.29]	−0.17 [−0.46, 0.11]	−0.24 [−0.53, 0.04]
Contact search rural	0.01 [−0.55, 0.57]	−0.01 [−0.63, 0.49]	0.15 [−0.14, 0.44]	0.11 [−0.29, 0.51]	0.15 [−0.24, 0.59]
Dialing urban	−0.17 [−0.65, 0.31]	0.10 [−0.39, 0.58]	−0.28 [−0.63, 0.08]	−0.04 [−0.38, 0.29]	−0.12 [−0.42, 0.20]
Dialing rural	0.01 [−0.59, 0.73]	−0.03 [−1.03, 0.30]	−0.14 [−0.43, 0.16]	**−0.60** [−0.94, −0.27]	0.15 [−0.24, 0.59]
Standard deviation of lane position					
Contact search urban	−0.001 [−0.24, 0.19]	−0.01 [−0.31, 0.14]	−0.10 [−0.26, 0.05]	−0.17 [−0.35, 0.01]	−0.10 [−0.23, 0.03]
Contact search rural	0.0002 [−0.43, 0.43]	−0.41 [−0.84, 0.02]	0.10 [−0.22, 0.43]	**−0.29** [−0.56, −0.03]	0.10 [−0.13, 0.37]
Dialing urban	0.17 [−0.31, 0.68]	−0.28 [−0.86, 0.19]	−0.01 [−0.32, 0.15]	**−0.56** [−1.07, −0.05]	−0.26 [−0.56, 0.03]
Dialing rural	0.18 [−0.33, 0.69]	−0.01 [−0.60, 0.43]	0.17 [−0.10, 0.44]	−0.07 [−0.49, 0.35]	−0.004 [−0.36, 0.35]

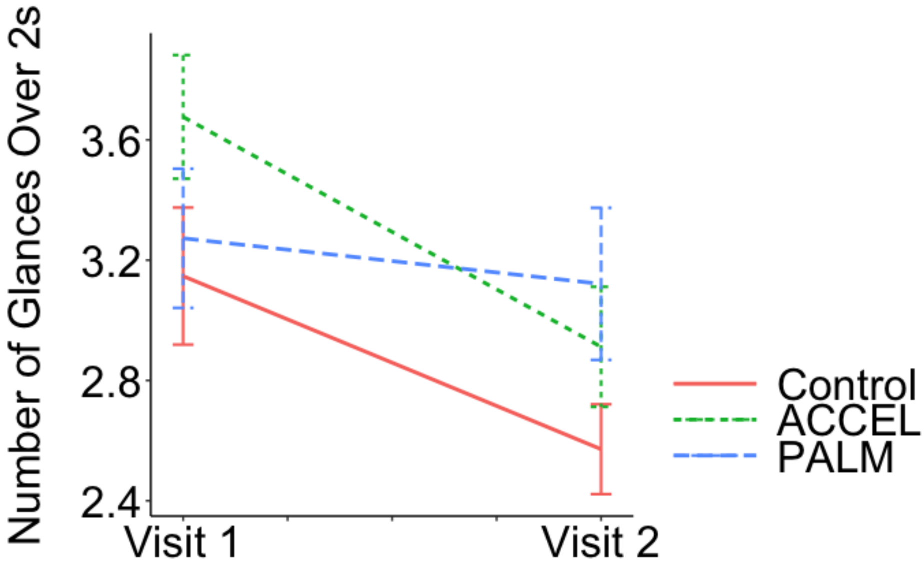

Figure 64. Number of glances greater than 2 seconds to in-vehicle task.

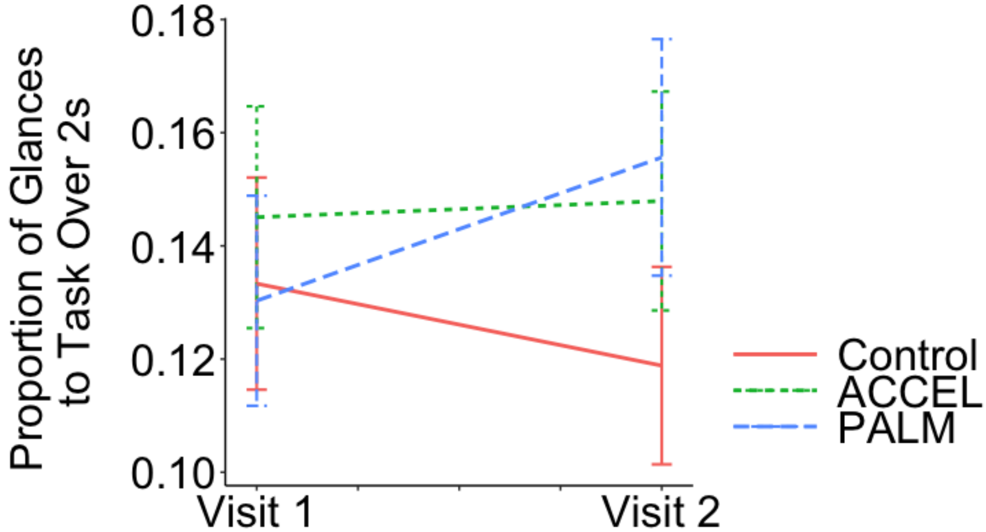

Figure 65. Proportion of glances greater than 2 seconds to in-vehicle task.

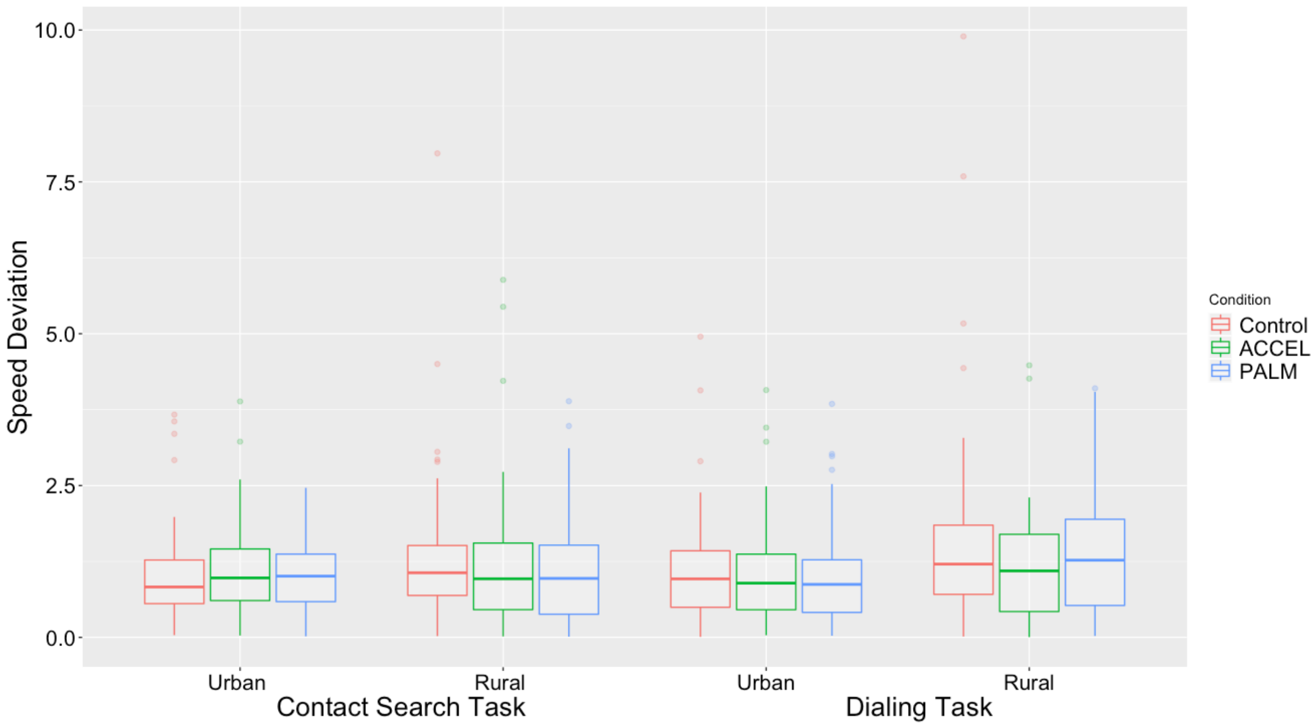

Figure 66. Standard deviation of speed (mph) for each of the secondary tasks.

Discussion

The goal of the current study was to examine the impact of two hazard anticipation programs, the Perceptual Adaptive Learning Module (PALM) and the Accelerated Curriculum to Create Effective Learning (ACCEL), on novice teen drivers' visual attention and driving performance in the context of potential hazards in a driving simulator. Newly licensed drivers with less than two weeks of unsupervised driving experience were recruited to participate. Participants were randomly assigned to one of three conditions: ACCEL training condition, PALM training condition, or the control condition. Participants completed a pre-test simulator drive at their first study visit that included a range of driving events. Event types were selected from both training programs. Following the pre-test simulator drive, those assigned to a training condition completed the training program on-site. Following six weeks of unsupervised driving, teens returned for a post-test visit in which they completed another, equivalent simulator drive. Overall, this evaluation found relatively few significant differences in the eye movement or driving performance measures as a result of hazard perception training. However, compared to controls, those in the ACCEL and PALM training conditions saw increases in glances and total looking time to the mid-block crosswalk and parallel parked car events, both of which were represented in both training programs. Those in the ACCEL condition also increased the total time spent glancing at the obscured cross-traffic lane—a hazard scenario included in the ACCEL training program. They also decreased the number of glances over 2 seconds to an in-vehicle distraction task at visit 2, which is a notable finding because the ACCEL training also included the skill of attention maintenance.

There does seem to be an effect of the ACCEL training for a small number of events, particularly those that were explicitly present in the training model. However, changes in eye glance and driving behavior were not consistent across events. For example, those who received the ACCEL training had more glances at the post-testing visit for the mid-block crosswalk and parallel parked car events, but showed decreases in glances at the post-test visit for the platoon event despite direct representation of this events in the training. Previous studies that have evaluated predecessors to the ACCEL training program or individual components of it (e.g., Risk Awareness and Perception Training [RAPT], SAFE-T) have also shown mixed results regarding the benefits of the hazard anticipation training. One such study failed to show an overall effect of the RAPT training on crash rates and traffic violations. However, the training did show a benefit for males who received the training (Thomas et al., 2016). Unlike the RAPT training, ACCEL also includes training in hazard mitigation and attention maintenance. Evaluation of the SAFE-T program, which also provides training in hazard mitigation and attention maintenance, showed a clear training benefit in all three categories (Yamani et al., 2016). The current study showed little to no change in mitigation maneuvers, yet ACCEL-trained participants exhibited a significant reduction in long glances away from the roadway. This is potentially important, as a substantial proportion of novice drivers' crashes have been shown to involve inattention to the forward roadway (Simons-Morton et al., 2014).

There also seems to be some benefit for the PALM training. However, like ACCEL, the benefits were not consistent across the events that were tested. For example, compared to control, those who received the PALM training exhibited increased glances at visit 2 to the mid-block crosswalk and parallel parked car events. Conversely, those in the PALM condition exhibited decreases in glance counts and total glance time when approaching the platoon events. Importantly, the events in which participants exhibited increases in glance counts and total looking time at visit 2 were directly represented in the training program. In contrast, scenarios in which there were decreases in these measures after training were not directly represented in the program. While no analogous programs exist specifically for driver training, PALM training programs in other domains such as medical training (e.g., Kellman, 2013; Kranse et al., 2013) have found robust and lasting benefits of the training.

It is possible that the PALM and ACCEL training programs had little effect—at least not effects that could be measured in simulated driving and that perpetuated six weeks after the training was completed. A prior evaluation of ACCEL (Fisher et al., 2017) was conducted in a driving simulator and was able to find effects of training. However, in that study performance was evaluated immediately after the participants completed the training, using a between-subjects study design that compared participants who had just received the training to untrained participants. In contrast, the current study compared the changes in participants performance approximately six weeks after training to their performance before the training. Notably, as a part of a longer-term follow-up evaluation supported by the SAFER-SIM University Transportation Center, preliminary data from a survey completed after a third study visit approximately six months after training shows that only approximately 40% of ACCEL participants and 48% of PALM participants agreed that they applied what they learned from the training while driving during the first month of the study.

Why are the two training programs not showing more robust improvements in hazard anticipation among the current sample? One possibility is that the effects of training exist but cannot be detected statistically with the selected measures due to wide variability in performance and the collapsing of performance data across conditions. As was the case for males in the RAPT training evaluation (Thomas et al., 2016), it may be the case that the training benefited certain drivers (e.g., those who were more or less proficient prior to training) more than others. As observed by the researchers, the participants in this study exhibited a wide range of baseline driving and scanning behaviors. Some teens seemed to appropriately scan, recognize, and respond to many of the potential hazards in the drives, while others did not. Recently, Mirman and colleagues (Mirman, 2019; Mirman et al., 2019) have proposed that reductions in crash rates observed at the population-level are not necessarily reflective of individual-level changes in crash risk. For example, a 10% reduction in crash rate at the population level could reflect that each driver's crash risk decreased by 10%, or that crash risk remained unchanged for three-quarters of the population but fell by 40% for the remaining one-quarter of the population, or any other such combination. More specifically, considering data from conditions in aggregate can misrepresent changes occurring at the level of the individual. Future analyses should attempt to examine changes at the individual level to investigate whether perhaps the training is particularly beneficial to a subset of drivers even if it does not have major benefits for all drivers.

Beyond not capturing individual differences in performance changes from pre- and post-testing, the six-week driving period between training and testing may have been too short for the effects of the training to manifest themselves in observable ways. While beyond the scope of the current report, this will be examined in a longer-term follow-up evaluation supported by the SAFER-SIM UTC in which the participants completed a third simulated drive six months after training. It may be the case that the additional time in which to encounter scenarios on the road similar to those in the training may result in further improvements in the trained participants relative to the untrained control group.

Similarly, the some of the dependent measures used in the current study might benefit from further refinement. For example, some events were visible to the driver prior to what the researchers have defined as the start of the event, which may require expanding the current event window. Given the wide variety of hazard events included in the simulator drives, dependent measures were selected with consideration of each specific event. However, it may be worth considering ways to standardize some dependent measures across events. One of these may be determining when responses (driving and eye measures) occur in relation to the distance to the hazard. Finally, composite measures of hazard "awareness" should be considered. Some drivers may respond to a potential hazard by releasing the accelerator while others may increase lateral distance to a hazard. Still other drivers may monitor a potential hazard by glancing at it several times as they approach. In all of these cases, the drivers recognized the potential hazard but their responses were diluted across different dependent measures. A composite measure looking across different dependent measures may reveal training effects not evident when examining each individual measure in isolation. As the analysis of data for the long-term study continues, efforts are underway to apply Endsley's three-level model of situation awareness (Endsley 1995; Katrahmani et al., 2017) to both eye glance and driving performance measures.

A limitation of our approach is that it is unknown how eye movement and driving performance in the simulator compare to scanning and driving behavior in the real world. Research study participants driving in a simulator were likely primed to expect "something to happen," especially after completing a training program, and were likely to be more observant or driving more mindfully than they normal would. On the other hand, it is possible that some participants viewed the simulator as an environment where it was safe to take risks that they would not normally take in real driving. Finally, it may be difficult to disentangle the effects of the training from the learning effects that result from completing multiple simulator drives. Despite creating multiple driving scenarios that varied the extraneous environmental cues surrounding events and counterbalancing the order of presentation, it is possible that participants recognized the events in the second simulated drive from having encountered them in their previous drive.

Based on participant opinions of the training programs, the ACCEL program could be improved by revising the instructions to be clearer and easier to understand. There might also be a benefit to attempting to streamline both programs, as most participants slightly agreed or agreed that both programs were too long and tiring. While the PALM participants agreed that the program was easy to use and understand, more than 80% agreed that they were already very aware of what they were being shown and about a third disagreed that they learned something new from the program. Although the instructions for PALM do state that the purpose of the training is to help the user recognize hazards and to do so quickly, it is possible that the participants were thinking about the specific hazard categories and scenarios that they experienced rather than the overall structure of the program when they completed the survey. Before either the ACCEL or PALM program is used outside of a research setting, revisions and additional usability testing should be completed.

Conclusions

While there seems to be some benefit associated with the programs examined, improvements in hazard detection and mitigation were only seen in a small number of events. More specifically, improvements seemed to be most robust when participants encountered events that were represented in the training. Additionally, determining what is being perceived about a potential hazard using eye tracking alone presents a number of challenges. Participants may have seen the hazard and returned to it several times, but still not understood the risk that it poses on the roadway. Conversely, if participants correctly identified an event as a hazard, glancing at the event longer may not benefit the driver. To further complicate this matter, some events such as the platoon braking event may require extensive monitoring to reduce crash risk, whereas a potential incursion may not warrant the same amount of visual attention. A number of studies have used talk-a-loud protocols to aid in this regard (e.g., Ahmadi et al., 2018) and future work using eye-tracking in a driving simulator might benefit from this approach.

Although this study does not provide strong evidence of efficacy of these programs, results should not be construed as evidence of lack of efficacy. Components of the ACCEL program, in particular, have shown significant positive effects in other studies. Further research is needed to understand how or whether training programs such as those examined in the current study affect the behavior and performance of young novice drivers.

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Appendix A – Participant enrollment summary by gender

Table 17. Enrollment summary for female participants.

	Enrolled	Visit 1 Complete	Visit 2 Complete	Complete with Eye Data
ACCEL	25	22	18	18
MSL	16	14	12	12
Intermediate	9	8	6	6
PALM	25	22	20	18
MSL	16	14	14	12
Intermediate	9	8	6	6
Control	23	20	18	18
MSL	15	14	12	12
Intermediate	8	6	6	6
Total	73	64	56	54
MSL	47	42	38	36
Intermediate	26	22	18	18

Table 18. Enrollment summary for male participants.

	Enrolled	Visit 1 Complete	Visit 2 Complete	Complete with Eye Data
ACCEL	20	19	18	17
MSL	11	11	10	10
Intermediate	9	8	8	7
PALM	19	18	16	15
MSL	12	11	10	9
Intermediate	7	7	6	6
Control	23	22	19	17
MSL	13	13	11	10
Intermediate	10	9	8	7
Total	62	59	53	49
MSL	36	35	31	29
Intermediate	26	24	22	20

Appendix B – PALM training data

Thirty-nine participants (22 female and 17 males) completed the PALM training program. The training program collected data about how many problems were attempted within each learning category and the outcomes. Through an unidentified issue, data for one of the female participants was not available at the end of the study. The time to complete the program ranged from 45 minutes to 137 minutes, M = 81, SD = 25. The number of problems seen during the training ranged from 60 to 174, M = 107, SD = 31. Both the time and number of problems to complete the training program were marginally more for females, $t(36) = 1.94$, $p = 0.06$, and $t(36) = 1.84$, $p = 0.07$. On average female completed 115 problems in 88 minutes while males completed 97 problems in 72 minutes. There were no differences in time or number of problems for license type or gender-license type combination.

Table 19 shows the training performance metrics for each of the PALM learning categories. Within each participant, each learning category was ranked 1 through 6, with 1 being assigned to the category with the fewest problems attempted before mastery is attained. The learning categories "Emergency vehicle effects" and "Anticipating lead vehicle slowing/stopping" were the easiest for participants to master, in about 13 problems. These were followed by "Anticipating roadside incursions" and "Anticipating vehicle coming into path," which required about 16 attempts on average to master. "Recognizing obscured potential hazard" took about 19 attempts while "Recognizing forced path change" took about 20 attempts to master. These results are very similar to those from the small usability study reported by Lerner et al. (2017).

Table 19. PALM training metrics by PALM learning category.

PALM learning category	Minimum problems attempted	Maximum problems attempted	Average problems attempted	Standard deviation problems attempted	Average accuracy	Average fluency	Average rank
Anticipating lead vehicle slowing/stopping	5	26	13.0	6.0	0.81	0.52	2.8
Anticipating roadside incursions	5	41	15.7	8.4	0.79	0.51	3.4
Anticipating vehicle coming into path	6	30	15.9	6.2	0.75	0.49	3.5
Emergency vehicle effects	6	31	12.5	5.3	0.78	0.66	2.7
Recognizing forced path change	5	39	20.3	8.8	0.71	0.49	4.5
Recognizing obscured potential hazard	7	42	18.8	9.2	0.68	0.49	4.2

Appendix C – Post training survey results

Table 20. Participants' agreement with statements after completing the ACCEL training program.

Statement	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
I learned something new from the program.	0%	2%	12%	32%	41%	12%
After using the program, I am better prepared to anticipate unexpected events on the road.	2%	5%	10%	40%	26%	17%
New drivers could learn a lot from the program.	0%	0%	2%	34%	32%	32%
I was already very aware of what was being shown on the training program.	0%	2%	24%	43%	24%	7%
The program was engaging.	5%	7%	27%	22%	34%	5%
I enjoyed the program.	2%	15%	24%	37%	15%	7%
The instructions were clear and easy to understand.	0%	10%	29%	17%	31%	14%
Most people could easily use the program without help.	0%	2%	17%	27%	32%	22%
The program was difficult to use.	14%	33%	17%	19%	17%	0%
I found the program to be tiring.	0%	10%	17%	45%	26%	2%
The program takes too long to complete.	0%	17%	24%	38%	19%	2%
I would prefer to complete the program over several, shorter training sessions.	12%	29%	19%	12%	19%	10%
Drivers would benefit from engaging in the training more than once.	2%	17%	14%	36%	21%	10%

Table 21. Participants' agreement with statements after completing the PALM training program.

Statement	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
I learned something new from the program.	13%	5%	15%	28%	28%	10%
After using the program, I am better prepared to anticipate unexpected events on the road.	5%	13%	8%	36%	26%	13%
New drivers could learn a lot from the program.	3%	3%	8%	15%	51%	21%
I was already very aware of what was being shown on the training program.	0%	5%	13%	41%	23%	18%
The program was engaging.	10%	10%	18%	28%	31%	3%
I enjoyed the program.	13%	13%	13%	24%	29%	8%
The instructions were clear and easy to understand.	0%	0%	3%	18%	51%	28%
Most people could easily use the program without help.	0%	3%	18%	10%	54%	15%
The program was difficult to use.	41%	33%	8%	15%	3%	0%
I found the program to be tiring.	3%	18%	10%	38%	13%	18%
The program takes too long to complete.	3%	13%	18%	26%	21%	21%
I would prefer to complete the program over several, shorter training sessions.	8%	31%	15%	13%	18%	15%
Drivers would benefit from engaging in the training more than once.	3%	23%	10%	28%	28%	8%

Appendix D – Mileage Log

Each week, teens reported their miles driven, the conditions in which they drove, and their general destinations (e.g., home, school, other) via Qualtrics. Below are the questions and logic used in the online survey.

Please report your starting odometer reading for the week:

____

Please report your ending odometer reading for the week:

____

How many days did you drive this week? (please enter a single number, not a range)

____

How many times did you drive to a destination other than home or school?

- O None
- O One
- O Two to three
- O Four or more

How many times did you drive at night this week?

- O None
- O One
- O Two to three
- O Four or more

How many times did you drive in heavy traffic this week?

- O None
- O One
- O Two to three
- O Four or more

How many times did you drive on a divided highway or interstate this week?

- O None
- O One
- O Two to three
- O Four or more

How many times this week did you drive on a 2-lane road where the speed limit was 55 MPH or more?

- O None
- O One
- O Two to three
- O Four or more

How many times did you drive in inclement weather (e.g., heavy rain, dense fog, snow) this week?

- O None
- O One
- O Two to three
- O Four or more

Did anyone else drive your car this week?

- O Yes
- O No

Display This Question:

If Did any one else drive your car this week? = Yes

How many miles were driven by another driver this week?

____

Did you received a driving citation in the past week?

O Yes

O No

Display This Question:

If Did you received a driving citation in the past week? = Yes

What was the citation?

____

Were you in a crash this week?

O Yes

O No

Were you grounded from driving this week?

O Yes

O No

Display This Question:

If Were you grounded from driving this week? = Yes

How many days were you grounded from driving?

____

Did you go on vacation this week?

O Yes

O No

Display This Question:

If Did you go on vacation this week? = Yes

Did you drive while on vacation?

O Yes

O No