Extended Evaluation of Training Programs to Accelerate Hazard Anticipation Skills in Novice Teens Drivers

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16. Abstract

The objective of this research effort was to evaluate two driver training programs by examining young driver performance and eye movements in a driving simulator. Training program content was assessed and potential hazards were selected across both programs for inclusion in the simulator drives. These were implemented as potential hazards that did not manifest. Each study drive included the same number and types of driving situations, though the order of appearance and scenery details varied by study drive. Teens ages 15 and 16 completed a baseline study drive within two weeks of obtaining a license allowing them to drive independently without a supervisor in the vehicle. Participants were randomly assigned to one of the training conditions or to control (no training). Those assigned to training completed the respective program immediately after the baseline study drive. Participants completed a second study drive after six weeks of independent driving experience. Funding from the SAFER-SIM UTC to conduct an extended evaluation supported a third study drive that occurred after approximately 24 weeks of independent driving. At each visit, participants completed a different version of the study drive. During all study drives, participants wore a head-mounted eye tracker and simulator driving performance was recorded. Eye movement data was manually coded for a select set of driving events. In addition, the eye and simulator data were combined for three events to create a composite measure based on Endsley's model of situation awareness

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Abstract

The objective of this research effort was to evaluate two driver training programs by examining young driver performance and eye movements in a driving simulator. Training program content was assessed and potential hazards were selected across both programs for inclusion in the simulator drives. These were implemented as potential hazards that did not manifest. Each study drive included the same number and types of driving situations, though the order of appearance and scenery details varied by study drive. Teens ages 15 and 16 completed a baseline study drive within two weeks of obtaining a license allowing them to drive independently without a supervisor in the vehicle. Participants were randomly assigned to one of the training conditions or to control (no training). Those assigned to training completed the respective program immediately after the baseline study drive. Participants completed a second study drive after six weeks of independent driving experience. Funding from the SAFER-SIM UTC to conduct an extended evaluation supported a third study drive that occurred after approximately 24 weeks of independent driving. At each visit, participants completed a different version of the study drive. During all study drives, participants wore a head-mounted eye tracker and simulator driving performance was recorded. Eye movement data was manually coded for a select set of driving events. In addition, the eye and simulator data were combined for three events to create a composite measure based on Endsley's model of situation awareness [1, 2].

Generally, the analysis of driver attention and driving mitigation of potential hazards reveled few significant differences among the training and control conditions. Among the significant findings observed for ACCEL, there seemed to be a positive impact with respect to hazard anticipation and mitigation. However, ACCEL was not found to improve attention maintenance relative to control during a phone dialing task. The significant results for PALM training suggested it may be effective at helping novice drivers identify, monitor, and respond to potential hazards, especially for those hazards directly represented in the PALM training.

1 Introduction

1.1 Background

Crash rates among young novice drivers are highest when they begin driving independently (e.g., [3]), are about ten times higher than those of learner drivers [4], and begin to decline quickly with increased driving experience [5]. 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. Among novice teen drivers, 45% of crashes have been attributed to a failure to identify emerging threats on the roadway [6]. Previous research (e.g., [7]) has observed that novice drivers perform the skill of hazard perception more poorly than experienced drivers and a number of hazard training programs have been developed and evaluated [8]. Recently, the AAA Foundation for Traffic Safety sponsored the creation of two training programs designed to accelerate the development of perceptual expertise (i.e., skill in efficiently and effectively responding to perceptual information about hazards in the roadway environment) and hazard anticipation skills in novice teen drivers, respectively, Perceptual Adaptive Learning Module (PALM) and Accelerated Curriculum to Create Effective Learning (ACCEL). The purpose of this research effort is to evaluate these novice driver training programs and ascertain whether they help to improve hazard anticipation and mitigation skills compared to the natural accumulation of driving experience. Funding from the AAA Foundation supported the baseline and 6-week post-training study visits while the SAFER-SIM UTC supported this extended evaluation based on a third, follow-up study visit completed approximately 18 weeks after the second. While the focus of this report is on the extended evaluation, results associated with the six-week follow-up are included for context. Though the methodological details are included in this report for completeness, much of the content—particularly descriptions of the scenario events and data collection procedures—is identical or similar to information in the AAA Foundation report associated with this research project [9].

1.2 Perceptual Adaptive Learning Module (PALM)

The Perceptual and Adaptive Learning Model [PALM; 10] 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., 11, 12], by optimizing the extraction of information through long-lasting improvements in perception and pattern recognition [13-15]. The PALM for novice drivers presents many short video episodes of potential hazards in six categories:

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.

A screenshot from a video associated with “anticipating that another vehicle may enter your path” is shown in Figure 1.1. Delivery of the PALM training program is done online via a web browser and randomly presents the videos across three trial types: “watch”, “respond”, and ‘no event.” During “respond” trials, users are asked to indicate when the hazard manifests by pressing the space bar. For both “watch” and “respond” trials, users identify from a multiple-choice list what type of hazard was the first key event shown in the video. The PALM program uses an algorithm that considers both the accuracy and speed of users' responses. Following their response, participants are given feedback about the accuracy of their response. If incorrect, the program provides users with the correct answer and allows the participant to replay the scenario to watch the hazard unfold again. 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.

Figure 1.1 - Screen shot from a respond trial in the PALM training [10]

1.3 Accelerated Curriculum to Create Effective Learning (ACCEL)

The ACCEL program [16] 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 main skill is presented in both strategic and tactical contexts. 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." The skills are presented in three different types of driving situations associated with increased crash risk for young drivers: intersections, rear-end, and curves.

ACCEL is delivered via in interactive PowerPoint presentation and aims for users to acquire the identified skills using an active method by which they are expected to make mistakes, are mentored to 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. For the hazard anticipation scenarios, users watch an animation and must 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 1.2. To conclude the sequence for each skill, the user is presented with the scenario a final time to ensure mastery. During attention maintenance scenarios, the user toggles between the driving scene and a visual search task and is advised when the visual search period exceeds 2 seconds.

Figure 1.2 - Screenshot from the ACCEL training program [16]

2 Methodology

2.1 Objective

The purpose of the current study was to evaluate the effect of the PALM or ACCEL training programs on the early detection and mitigation of potential roadway hazards among newly-licensed young drivers over and above the attainment of these skills during the first six months of unsupervised driving.

2.2 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. Those assigned to the PALM and ACCEL conditions completed the training program immediately after the baseline study drive. After six weeks of driving experience, each participant completed a second simulator drive. Most participants returned for a third simulator drive about eighteen weeks after the second one. The pre-test, post-test design used here is a powerful tool in determining change in hazard anticipation skills because 1) each participants serves as their own control, and 2) this method provides a means of determining how performance changes in response to the training programs compared to normal driving experience.

2.3 Participants

Teen drivers between the ages of 15 and <17 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. Most study participants resided within one hour of the University of Iowa. A summary of participant enrollment and study completion is given in Table 2.1 and enrollment by gender can be found in Appendix A. For this study, 83 participants were obtaining a minor school license and 52 were obtaining an intermediate license at the time of enrollment.

Participant attrition occurred for a variety of reasons. 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 2.1 - Enrollment and study completion by Condition and License type

		Completed Visits			Completed Visits with Eye Data	
	Enrolled	Visit 1	Visit 2	Visit 3	Visit 2	Visit 3
ACCEL	47	43	35	31	34	30
MSL	27	26	21	19	21	19
INT	20	17	14	12	13	11
PALM	46	40	35	30	34	30
MSL	28	24	23	18	22	18
INT	18	16	12	12	12	12
Control	48	45	38	29	35	29
MSL	28	28	24	18	22	18
INT	20	17	14	11	13	11
Total	141	128	108	90	103	89
MSL	83	78	68	55	65	55
INT	58	50	40	35	38	34

2.4 NADS-2 simulator

The NADS-2 (see Figure 2.1) 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 2.1 - NADS-2 driving simulator

2.5 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 2.2). 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 2.3. 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 eye point.

Figure 2.2 - Participant wearing Dikablis eye tracking glasses in NADS-2

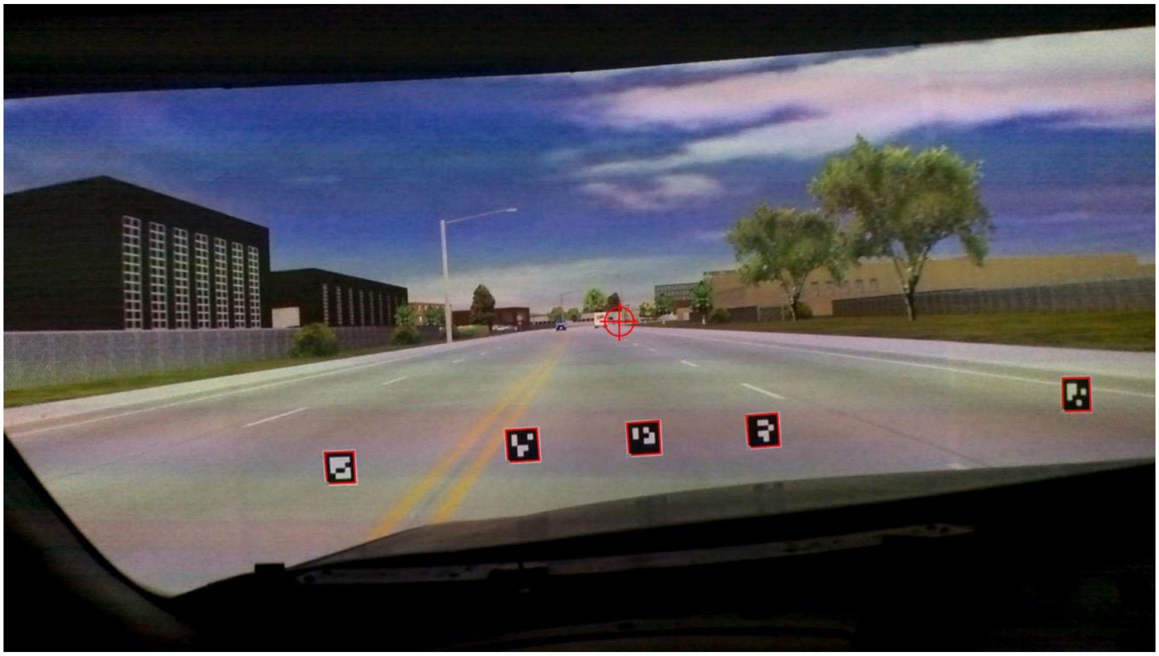

Figure 2.3 - Forward scene camera view recorded by Dikablis eye tracking glasses as viewed in D-Lab software with gaze cursor overlay and reference markers

2.6 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 (e.g., “Please drive in the left 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 speed limit decreased to 30 mph, the roadway passed through a brief residential area at the edge of a town, 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.

A practice simulator drive was also designed to help familiarize the participants with the simulator. The practice drive did not contain any hazards but did contain similar driving environments to the study drive (described below). The practice drive took approximately 8 minutes to complete.

2.7 Scenario events

Each drive included 25 “events.” There were three types of events:

- 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.
- Driving while completing a secondary task with an in-vehicle touchscreen display, with consideration toward the attention maintenance skill training of ACCEL.
- 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. Events were marked in the simulator data using a user-specified data element called log streams. These event markers were also sent across a configured network connection to the D-Lab software to be logged in the eye tracking data. For each event, a window of analysis was defined for data analysis. For some potential hazard events where eye movement data were coded, a second window closer to the hazard was also specified. This close proximity period represents the critical window during which, if the potential hazard were to materialize, mitigation would be necessary to avoid a collision.

2.7.1 Potential hazard events

The potentially hazardous events were categorized with respect to the training programs, ACCEL and PALM (see Table 2.2). 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. These events had the potential to be hazardous, for example, a vehicle or a pedestrian that might enter the vehicle's path, but the hazards did not materialize. Altogether, fifteen potential hazard events were selected from the training programs for inclusion in the simulator drives.

Table 2.2 - Event categories with respect to the ACCEL and PALM training programs

Event Category	Definition: 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
ACCEL unique	Included in ACCEL and nothing in PALM is similar
PALM unique	Included in PALM and nothing in ACCEL is similar

2.7.1.1 Mid-block crosswalk

Event category: Near/Near

The participant was driving in the left lane of a city street with two lanes in each direction. Ahead there was 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 2.4). Pedestrians could be seen walking on the sidewalk to the right of the large vehicle heading 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 2.5). The event window began when the participant was 695 feet from the crosswalk. The close proximity period began approximately 250 feet from the crosswalk.

Figure 2.4 - Participant's view of the mid-block crosswalk event

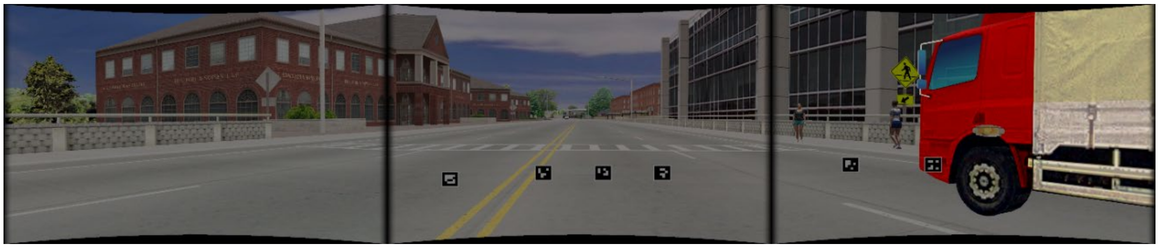

Figure 2.5 - Participant's view of the pedestrians that have been obscured by the stopped vehicle in the mid-block crosswalk event

2.7.1.2 Parallel parked car

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 2.6). Coding of the eye data began as soon as the parallel parked car was visible, at of a distance of approximately 700 feet. The close proximity period began 300 feet from the parked car.

2.7.1.3 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 2.7). The eye coding

Figure 2.6 - Participant’s view of the parallel parked car event

Figure 2.7 - Participant’s view of the obscured cross-traffic lane event

window began when the bus became visible (about 271 feet from the bus when the participant was in the right lane and about 346 feet from the bus when in the left lane).The close proximity period began as shown in the figure, when the participant's line of sight began to reveal the obscured lane, which was about 160 feet from the bus if they were driving in the center of the right lane and about 200 feet if they were driving in the center of the left lane.

2.7.1.4 Potential vehicle incursion

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 2.8). 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.

2.7.1.5 Partial lane obstruction

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 2.9). The window of analysis began when the participant was about 465 feet from the obstructing vehicle.

Figure 2.8 - Participant’s view of one the potential incursion events

Figure 2.9 - Participant’s view of one the partial lane obstruction events

2.7.1.6 Dynamic object

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 2.10). The window of analysis began when the participant was about 400 feet from the dynamic object.

2.7.1.7 Work zone lane closure

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 2.11a), preceded the lane closure (see Figure 2.11b). 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. The window of analysis began when the participant was about 1955 feet from the first channelizer in the work zone and ended 300 feet into the work zone.

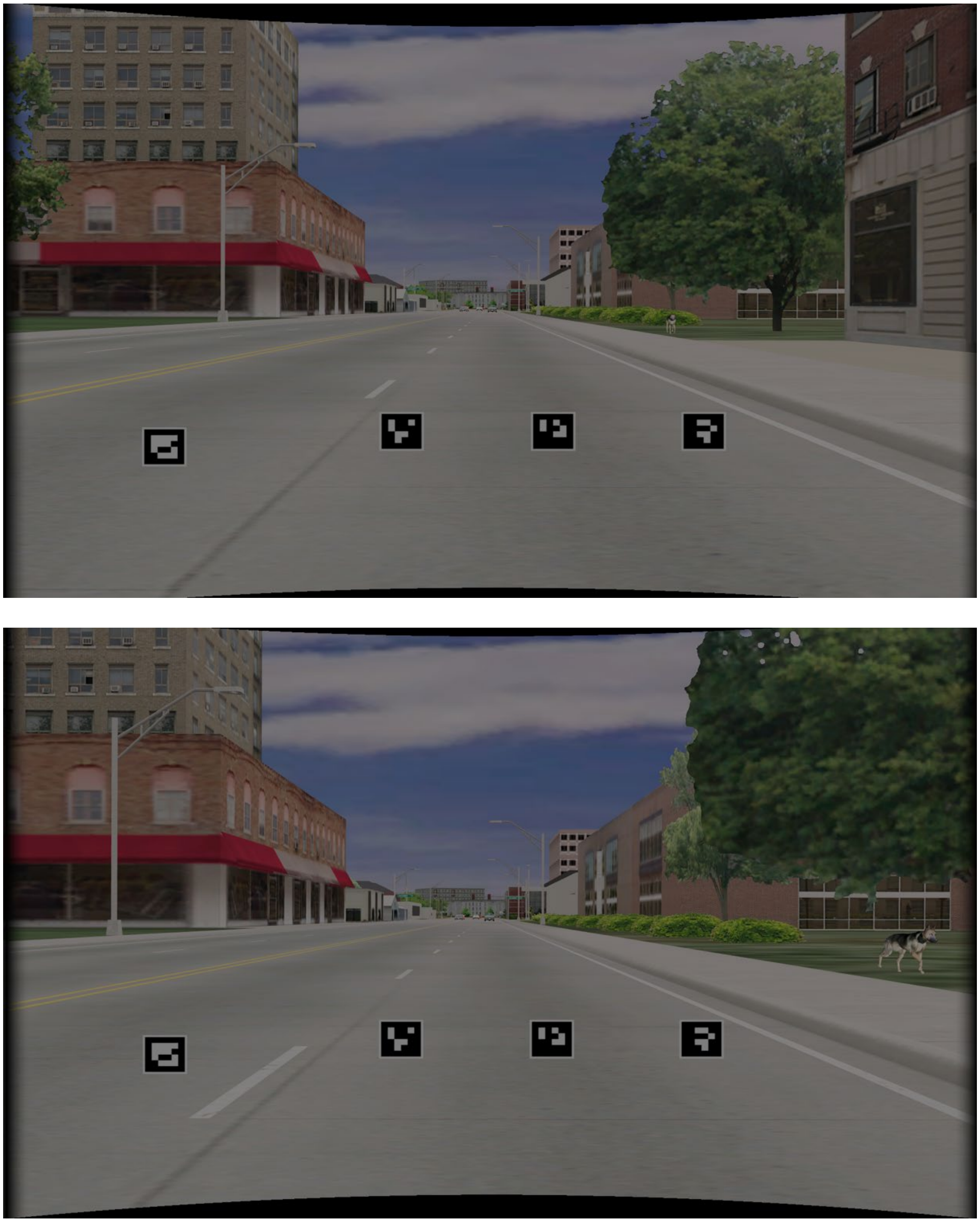

Figure 2.10 - Participant's view of one of the dynamic objects event at two distances

Figure 2.11 - Participant's view of one of the work zone lane closure event at two instances

2.7.1.8 Lane drop

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 2.12). The window of analysis began when the participant was about 610 feet from the location where the right lane began to close and ended when the right lane was completely closed.

Figure 2.12 - Participant's view of the transition from 4-lane to 2-lane event

2.7.1.9 90-degree curve

Event category: ACCEL unique

The participant was traveling in a residential area with one lane in each direction and was approaching a tight 90-degree small radius curve to the right (radius of 200 feet) with line of sight around the corner obscured. There was a warning sign with the posted advisory speed of 20 mph (see Figure 2.13a) 775 feet before the curve followed by a second warning sign without a speed placard (see Figure 2.13b) 100 feet before the curve. The window of analysis was from about 965 before the start of the curve through the end of the curve.

Figure 2.13 - Participant's view of the 90-degree curve event at two distances

2.7.1.10 Platoon braking

Event category: ACCEL near/PALM far

The participant was driving on a city street with two lanes in each direction. Ahead in 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 2.14) 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 come on the first time and ended 7 seconds after the platoon vehicle's brake lights came on the second time.

Figure 2.14 - Participant's view of the platoon braking event

2.7.1.11 Obscured T-intersection

Event category: ACCEL near/PALM far

The participant was traveling on 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 2.15a). The intersection itself was partly obscured (see Figure 2.15b). 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.

2.7.1.12 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 2.16 for an example). The brake lights of the following vehicle were illuminated and the vehicle comes to a stop behind the slowing/stop lead vehicle.

2.7.1.13 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 2.17.

Figure 2.15 - Participant's view of one of the obscured t-intersection events at two instances

Figure 2.16 - Participant's view of one of the left lane impeded events

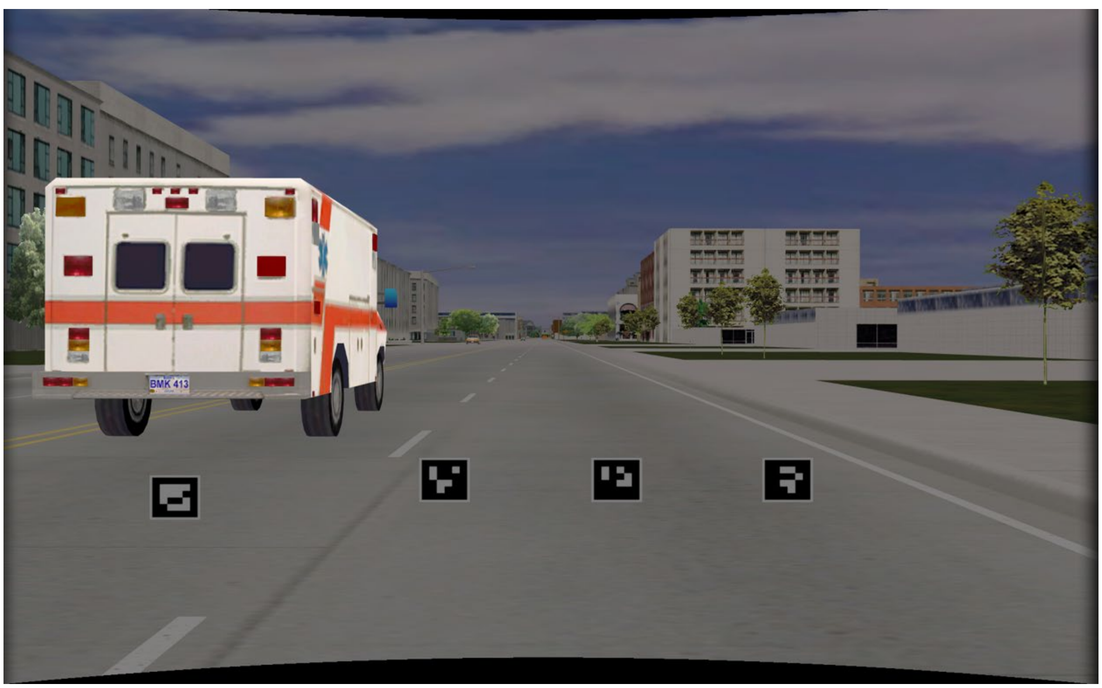

Figure 2.17 - Participant's view of one of the ambulance events after being overtaken by the ambulance

2.7.1.14 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 2.18).

Figure 2.18 - Participant's view of one of the intermittent lead vehicle braking events

2.7.1.15 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 2.19).

Figure 2.19 - Participant's view of the fire station event

2.7.2 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 2.20) and the phone number was repeated a second time. The participant dialed the phone number, pressed the dial button to connect (see Figure 2.21) 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 2.22) 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 2.23. Most participants took at least 10 seconds to perform each task.

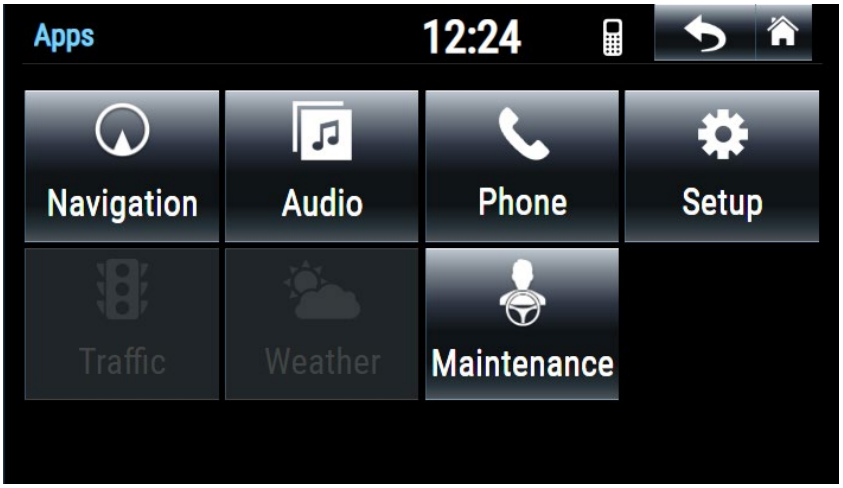

Figure 2.20 - Touchscreen display at the beginning of each secondary task

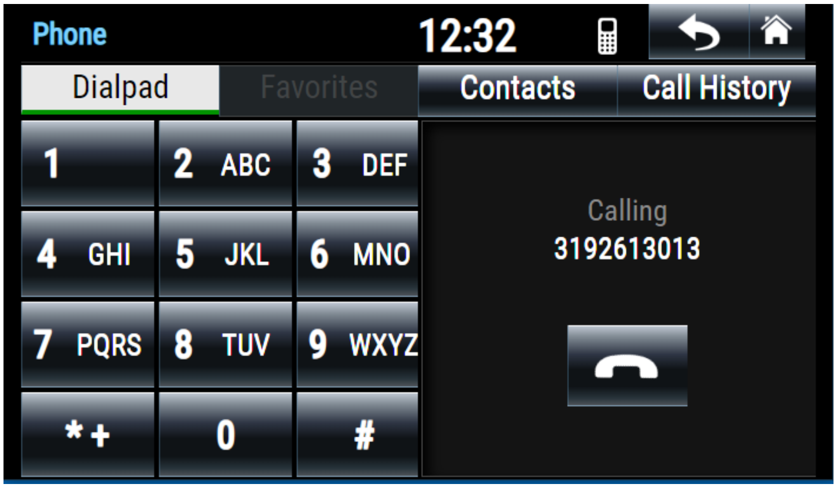

Figure 2.21 - Touchscreen display after connecting a call by dialing

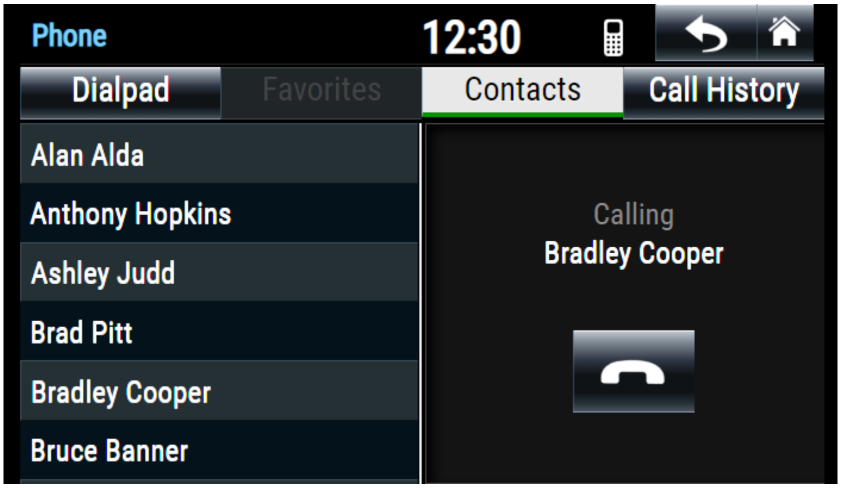

Figure 2.22 - Touchscreen display after connecting a call by selecting a contact

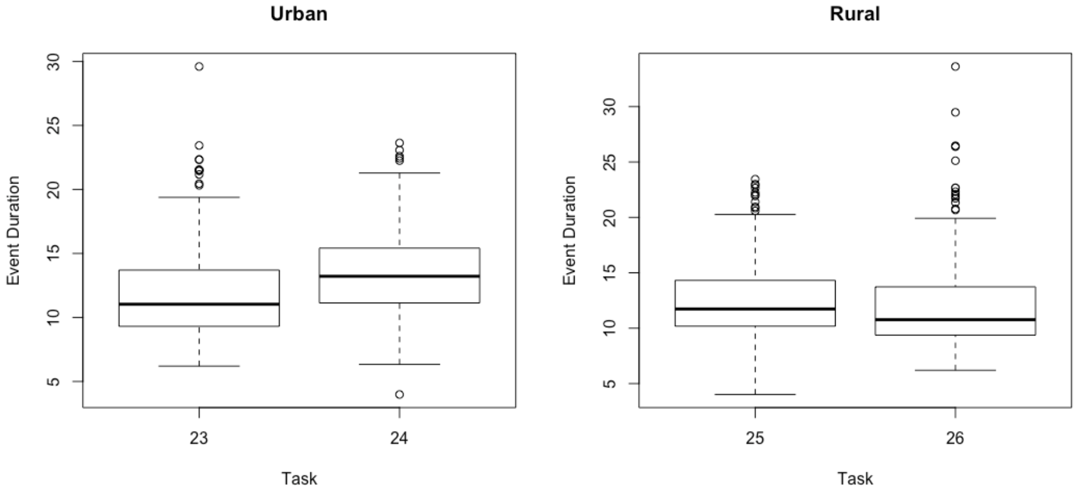

Figure 2.23 - Boxplot of event duration (seconds) for each of the secondary tasks. Tasks 23 and 26 were dialing a phone number and tasks 24 and 25 were contact search tasks

2.7.3 Normal driving events

The drives also contained periods of driving without potential hazard events or secondary tasks, described in Table 2.3.

Table 2.3 - Normal driving event descriptions

Event Category	Definition: This type of event is…
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 2.24).
4-way stop sign with traffic present	The participant was traveling on a residential street. As he 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 2.25).
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 2.24 - Participant's view of the school zone at two distances

Figure 2.25 - Participant's view of the 4-way stop intersection with traffic present

2.8 Study visits

2.8.1 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 PowerPoint 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, adjust the rearview mirror, and put on their seatbelt. 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 the 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, 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 and if the participant did not feel well, their participation in the study ended.

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

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 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 B). The researcher read a debriefing statement that asked the participants not to discuss details from the study with other teens who might be eligible to participate. 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 and/or email and completed the survey via Qualtrics.

2.8.2 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 PowerPoint 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. The wellness survey was completed again at the end of the experimental drive.

2.8.3 Visit 3

The third visit was scheduled to coincide with participants’ 24th week of independent driving experience. As with visit 2, participants began the session by viewing the training PowerPoint for the driving simulator, were escorted to the simulator, and outfitted with the eye tracker. Following eye tracker calibration, participants again received instructions for the secondary tasks and completed the practice drive. After the practice drive, participants completed the wellness survey. If participants did not meet the threshold for simulator sickness, they then completed the 22-minute experimental drive. The wellness survey was completed again at the end of the experimental drive.

2.9 Driving performance data

2.9.1 Driving simulator data reduction

The NADS-2 outputs a DAQ file that contains numerous subsets of simulator data recorded by various simulator subsystems. Systematic data reduction procedures in MATLAB process this raw file and resample the data subsets 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; and lane position. The data also included the position, velocity, and acceleration of every dynamic object simulated in the virtual world; the log streams which marked the location of the various events in the data; and 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.

2.9.2 Driving performance dependent measures

<u>Accelerator release</u> 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). If an accelerator release was noted, then the distance the participant vehicle had traveled since the start of the event and the distance remaining until the end of the event or the location of the hazard were also calculated.

<u>Brake press</u> – 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, distances were calculated in the same manner as for accelerator release.

<u>Lane change</u> – A lane change was noted when the center of the participant vehicle crossed a lane boundary. If a lane change was identified, distances were calculated in the same manner as for accelerator release.

<u>Lane shift</u> – If the participant vehicle shifted left more than three feet from its initial lane position at the beginning of the event window due to a potential hazard located on the right side of the roadway, a lane shift was noted. If a lane shift was identified, 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.

Standard deviation of lateral position –standard deviation of the participant vehicle position in the lateral direction.

2.10 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 after the calibration procedures and this caused the gaze cursor projected onto the forward scene to be 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 areas of interest (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 selected a subset of events for manual coding.

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 were calculated using intraclass correlations (ICC) and ranged between ICC = .96 and ICC = .99. The categorical variable coded to determine when participants looked to the pedestrians was calculated using Cohen's kappa (and ranged between *K* = .61 and *K* = .81).

2.10.1 Eye movement data coding and processing

Coding the eye data involved several steps. First analysts reviewed both pupil tracking and gaze calibration and made corrections in the Ergoneers D-Lab software. Then the timing of the event markers sent from the simulator to the D-Lab software were entered into the Notes file for that recording. Next the analysts who had been trained and verified to code that specific event coded the start and end of each glance to the target area(s) defined for that event. Then the Notes file for each recording was exported to a text file. Individual text files were cleaned, checked for completeness and accuracy, and backed up on a NADS data server. The individual text files were imported into SAS to compile the eye movement data set for each event. Any missing values were noted and the individual text files were updated. The final eye movement data set included time of each event marker, the start and end of each glance to the hazard, and the location of glances for certain events.

2.10.2 Eye movement dependent measures

Eye dependent measures were calculated using MATLAB. Only glances greater than 100ms were analyzed.

<u>Time to first glance</u> – Time from the start of the event window until the first glance at a hazard location

<u>Total looking time</u> – The total duration of the total number of glances made to the hazard location(s) during the event window and, if applicable, during the close proximity period.

Percentage of event window (or close proximity period) looking at hazard – The total looking time divided by the duration of the event window (or, if applicable, the close proximity period).

Distance to the hazard for first glance – The distance to the hazard when the participant first glanced at the hazard.

Distance to the hazard for last glance – The distance to the hazard when the participant initiated their last glance at the hazard.

Proportion of long glances away from the road – Number of glances away from the roadway lasting longer than 2 seconds divided by the total number of glances away from roadway during the urban dialing task.

2.11 Situation awareness measures

In order to quantify the subjects' awareness of the potential hazard in the driving scenario, we adapted the approach of Katrahmani et al. [2, 17, 18], which mapped eye movements and hazard mitigating driving behaviors to Endsley's model of situation awareness [1]. These situation awareness measures were not included in our previous report [9]. If a subject made a glance to potential hazard, it was classified as level 1 (perception). If the subject looked at the potential hazard for longer than 1 second or made a second glance to it, it was classified as level 2 (comprehension). Level 3 situation awareness (projection) was achieved if the subject either:

1. had reached level 2 and then either

   a) made a new glance to the hazard in the close proximity period or

   b) reached a total glance time (total looking time) of more than 2 seconds while in the close proximity period, whichever occurred first, or

2. had reached level 1 and then made a mitigating driving behavior (e.g., released the accelerator pedal, pressed the brake pedal, or moved laterally away from the hazard) that was appropriate for the specific hazard.

In other words, level 3 was achieved if the subject continued to visually monitor the hazard as he or she approached it, or after having looked at the hazard, took action to mitigate it.

The situation awareness levels were determined using MATLAB scripts. First the start and end times for the eye glance observations and event markers logged in the eye tracking data were converted from units of milliseconds to simulator frames at a frequency of 60 Hz. Then the event markers in the eye data were compared with the event markers in the simulator log stream. For about 2-6% of the data, the markers in the eye data had to be adjusted to account for lag in the network connection. Then the eye glances were aligned with the simulator data. MATLAB code examined the eye data to classify situation awareness according to the above criteria. The situation awareness dependent measure considered in this analysis was the highest level of situation awareness observed during the event window.

2.12 Analytical methods

Continuous dependent measures were analyzed using mixed-effects linear regression. All continuous measures using distance to the event as the dependent measures were excessively skewed and thus transformed using the natural log prior to analysis. The bivariate measure of accelerator release was analyzed using mixed-effect logistic regression. Models included fixed effects of Condition (ACCEL, PALM, Control), Visit (Visit 1, Visit 2, Visit 3), and their interaction. A random effects structure was included to increase the predictive power of the model. Loglikelihood testing was used to determine the random effects structure best suited to the data and included a random intercept of participant, which controlled for non-repeatable characteristics of the individual. 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. Note that the total number of miles driven was excessively skewed and thus transformed using the natural log. The model term of primary interest was the Condition x Visit interaction, which represented the average change in the dependent variable for visits 2 and 3 with respect to visit 1 within each training group as compared to the control. The ACCEL and PALM conditions were not compared to one another, as the purpose of the evaluation was to determine the impact of each training program relative to the natural accumulation of driving experience, not to compare them to one another.

3 Results

Due to the need for extensive manual coding of the eye data, the following analysis does not cover all of the hazard events represented in the simulator drives. Additionally, not all dependent measures are analyzed for each event. Rather, the study team identified the measures best suited to represent hazard anticipation and mitigation by event. For example, when passing an object that partially obstructs the driver's lane of travel, lateral position in the lane is an appropriate measure of driving mitigation. However, this measure is not appropriate when considering a lane drop where a lane change is not only expected, but entirely necessary. Additionally, some events lent themselves to glance related measures (e.g., midblock crosswalk), while others were better suited to simulator measures (e.g., work zone). In cases where situational awareness was considered, driving performance measures were not analyzed, as these measures were incorporated into the composite situational awareness measure.

3.1 Mid-block crosswalk event

The midblock crosswalk event represents concepts covered by both training programs. Analysis of the mid-block crosswalk examined glance, simulator, and situational awareness measures. Glance measures included the distance to the crosswalk at first and last glance to the hazard and the distance to the crosswalk when the participant first glanced past the front of the truck obscuring the view of the pedestrians. Additional glance measures included the percentage of the entire event window and close proximity period that the participant glanced at the hazard. Minimum speed was the only simulator measure considered. The maximum level of situational awareness achieved was the primary measure of interest related to situational awareness. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.1.

The distance to the crosswalk when participants made their first and last glances to the hazard did not vary by Condition, Visit, or their interactions. However, the model predicting the distance to the crosswalk at the time when participants first glanced to pedestrians in front of the obscuring truck revealed a significant Condition x Visit interaction for those in the ACCEL condition compared to controls at visit 3 (Figure 3.1). When examined by Condition, Visit predicted an increase in the distance at which participants first glanced to the pedestrian at visit 3 compared to visit 1 for participants assigned to the ACCEL condition, b = -.34, t (48) = 2.39, p = .02. Conversely, Visit predicted a reduction in the distance at which participants in the control condition first glanced to the pedestrian at visit 3 compared to visit 1, b = -.34, t (41.04) = -2.17, p = .04. Those in the ACCEL condition first glanced at the pedestrians, on average, 43.94 ft, sooner at visit 3 compared to visit 1, whereas those in the control condition glanced at the pedestrians an average of 23.54 ft later at visit 3 than at visit 1.

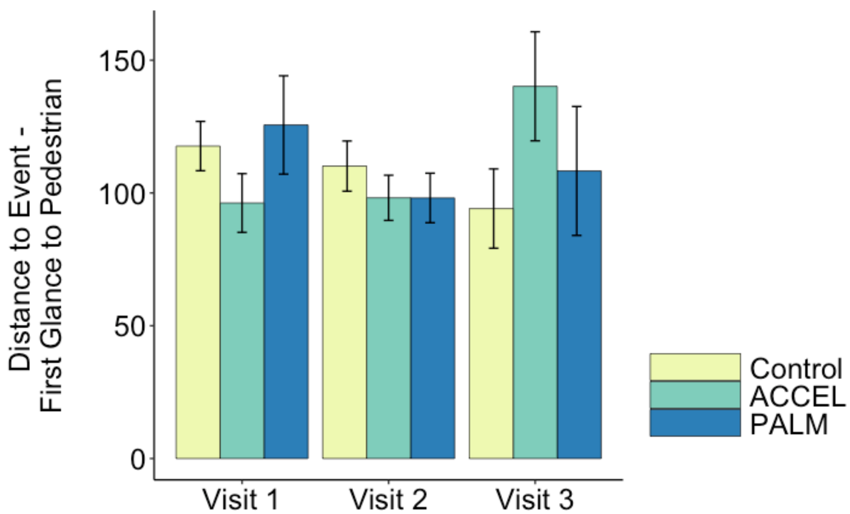

Figure 3.1 - Distance to the hazard at the first glance to the pedestrian during the mid-block crosswalk event

The percentage of the entire event window spent glancing at the hazard revealed a significant main effect of Condition. Compared to those in control, those in the PALM condition spent slightly less time (as a proportion) glancing at the hazard (Figure 3.2). This effect is likely driven by the between-Condition differences observed at visit 1. Condition, Visit, and their interaction did not predict the percentage of time spent looking to the hazard during the close proximity period.

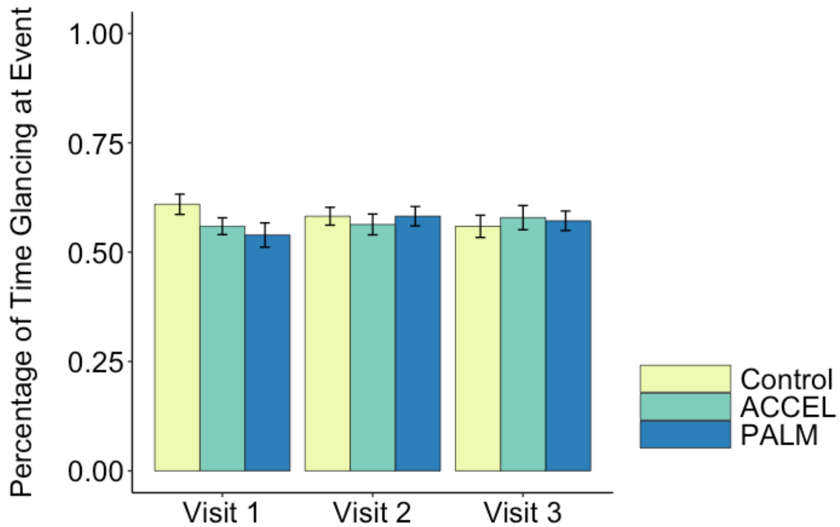

Figure 3.2 - Percentage of entire event window spent glancing to the mid-block crosswalk event

Analysis of minimum speed did not indicate associations of Condition, Visit, or their interactions.

The maximum level of situation awareness achieved was nearly uniform across all Conditions and Visits, with nearly all participants reaching SA level 3. No main effects or interactions reached significance for this measure.

Table 3.1 - Model results predicting eye glance and situational awareness from Condition and Visit for the mid-block crosswalk event

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Glance								
Distance to event at first glance	01. [-.07, .05]	-.04 [-.10, .03]	.02 [-.04, .08]	.02 [-.05, .08]	-.01 [-.05, .03]	-.03 [-.08, .01]	.003 [-.04, .05]	.01 [-.01, .01]
Distance to event at last glance	.14 [-.24, .53]	.35 [-.06, .75]	-.31 [-.69, .08]	.14 [-.27, .54]	-.08 [-.38, .21]	.08 [-.23, .38]	.05 [-.22, .32]	-.18 [-.47, .11]
Percentage of glance time during the entire event window	.04 [-.05, .12]	.07 [-.02, .16]	.07 [-.01, .15]	.08 [-.004, .17]	-.05 [-.11, .01]	**-.08** [-.14, -.01]	-.03 [-.09, .03]	-.05 [-.11, .02]
Distance to hazard at glance to pedestrians	.06 [-.33, .45]	**.69** [.28, 1.10]	-.10 [-.47, .26]	.14 [-.28, .55]	-.17 [-.48, .13]	-.02 [-.31, .28]	-.06 [-.32, .18]	-.37 [-.66, -.09]
Percentage of glance time during the close proximity period	-.004 [-.13, .12]	.11 [-.02, .24]	.02 [-.10, .14]	.02 [-.11, .15]	-.07 [-.16, .02]	-.05 [-.14, .04]	.01 [-.08, ,09]	-.04 [-.13, .05]
Situational Awareness								
Maximum SA	.001 [-.04, .04]	.001 [-,04, .04]	.03 [-.01, .07]	.03 [-.01, .07]	.004 [-.03, .03]	-.03 [-.06, .01]	.0000 [-.03, .03]	.0002 [-.03, .03]

3.2 Parallel parked car event

Analysis of the parallel parked car event consisted of glance and situational awareness measures. Analyses of glance measures were the distance to the hazard for first and last glances as well as the percentage of the entire event window and close proximity period that the participants glanced at the hazard. The maximum level of situational awareness achieved was the primary measure of interest related to situational awareness. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.2.

Analysis of the distances to the hazard at the first glance and at last glance did not reveal main effects of Condition, Visit, or their interaction. However, the percentage of time spent looking at the hazard over the entire event window was significantly associated with Visit such that participants spent 8% more time looking at the potential hazard at visit 3 when compared to visit 1 (Figure 3.3). While the results are not statistically significant, there seems to be a tendency for those in the training conditions to spend slight more of the event window looking at the hazard, whereas controls do not show a similar increase visit 3. The model predicting the percentage of time spent glancing at the hazard in the close proximity period did not reveal main effects of Condition, Visit, or their interactions.

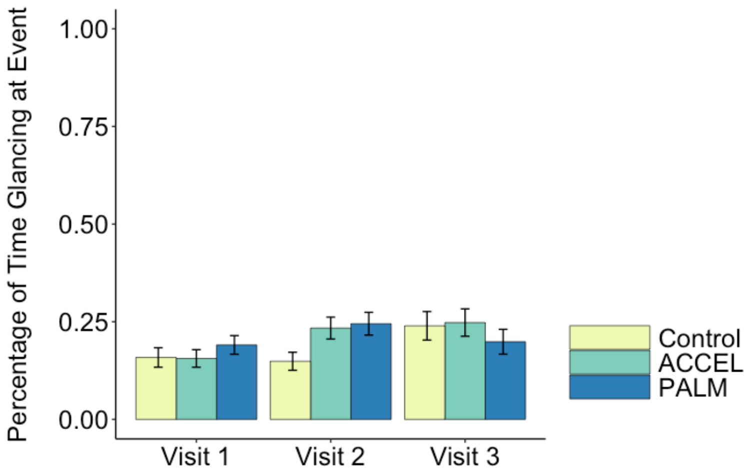

Figure 3.3 - Percentage of event window spent glancing to parallel parked car by Condition and Visit

The model predicting the level of situational awareness achieved by the participants revealed significant interactions of Condition x Visit for both PALM and ACCEL at visit 2 when compared to visit 1 (Figure 3.4). When examined by Condition, Visit marginally predicted an increase in situational awareness for participants in both training conditions at visit 2: PALM, b = .39, t (62.62) = 1.86, p = .06, and ACCEL, b = .33, t (59.49) = 1.77, p = .08. Visit did not significantly predict situational awareness for controls. This indicates that participants in the training conditions showed a significant improvement in situational awareness level following the training, whereas those who did not receive training showed no improvement. However, these gains for the training groups did not persist for visit 3.

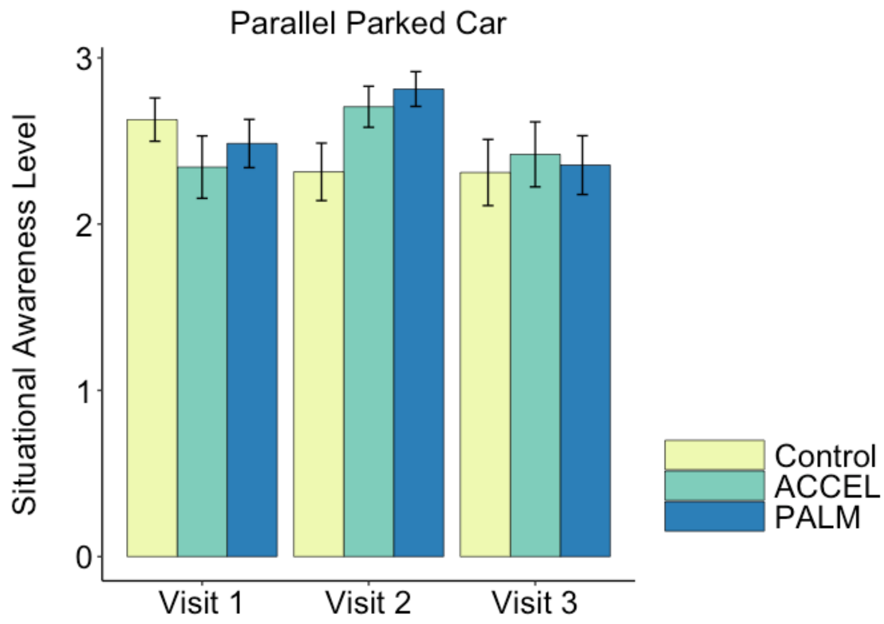

Figure 3.4 - Maximum level of situational awareness achieved during the parallel parked car event by Condition and Visit

The parallel parked car event represented hazard events found in both the ACCEL and PALM training programs. The results demonstrated significant effects of both the ACCEL and PALM trainings. Specifically, both training groups showed significant increase in situation awareness during visit 2. In addition there was a slight tendency for participants to spend more of the event window glancing at the hazard after training.

Table 3.2 - Model results predicting eye glance and situational awareness from Condition and Visit for the parallel parked car

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Glance								
Distance to event at first glance	.04 [-.24, .31]	-.03 [-.33, .26]	.06 [-.21, .33]	-.09 [-.38, .20]	-.004 [-.20, .20]	.06 [-.13, .26]	-.10 [-.29, .09]	.07 [-.07, .04]
Distance to event at last glance	-.22 [-.65, .21]	-.24 [-.70, .22]	-.31 [-.74, .12]	-.13 [-.59, .32]	-.08 [-.41, .26]	.09 [-.24, .42]	-.02 [-.32, .29]	.11 [-.22, .43]
Percentage of glance time during the entire event window	.08 [-.01, .18]	.02 [-.08, .11]	.06 [-.03, .16]	-.07 [-.17, .03]	-.003 [-.08, .07]	.03 [-.04, .11]	-.01 [-.08, .06]	**.08** [.01, .15]
Percentage of glance time during the close proximity period	.10 [-.04, .25]	.06 [-.09, .22]	.07 [-.08, .21]	-.08 [-.23, .07]	.01 [-.10, .12]	.07 [-.05, .18]	.01 [-.09, .11]	.09 [-.02,.20]
Situational Awareness								
Maximum SA	**.67** [.10, .24]	.41 [-.19, 1.00]	**.64** [.07, 1.22]	.20 [-.40, .79]	-.29 [-.73, .14]	-.18 [-.64, .27]	-.31 [-.71, .09]	-.33 [-.75, .09]

3.3 Obscured cross traffic lane

Analysis of obscured cross traffic lane consisted of glance and situational awareness measures. Analyses of glance measures included the distance to the hazard at first and last glance as well as the percentage of the entire event window and close proximity period that was spent glancing at the hazard. The maximum level of situational awareness achieved was the primary measure of interest related to situational awareness. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.3.

Analysis of the distance from the hazard when participant made their first glance to the hazard revealed a significant main effect of Condition when comparing ACCEL and control (Figure 3.5), such that those in the ACCEL condition were closer to the event at first glance. Similarly, Condition marginally predicted a decrease in the distance at which

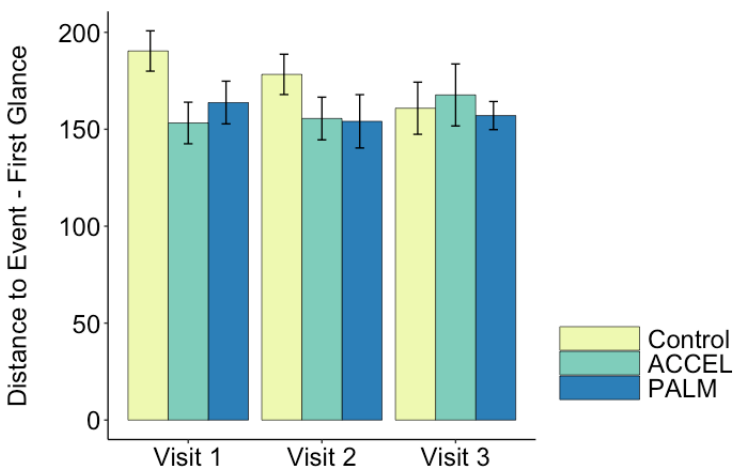

Figure 3.5 - Distance to the hazard at first glance for the obscured cross traffic lane

ACCEL participants made their last glance to the hazard compared to control. Visit also significantly predicted a reduction in the distance at which participants made their last glance at visit 3 compared to visit 2 (Figure 3.6).

The model predicting the maximum level of situational awareness achieved in the obscured cross traffic event did not reveal significant associations of Condition, Visit, or their interactions.

The obscured cross traffic scenario was chosen to directly represent training from the ACCEL program, but also represented similar concepts from the PALM training. The significant results observed for distance to the hazard at first and last glance largely stem from the fact that those in the control condition looked to the event sooner at visit 1 than the training groups. Overall, the distance to the hazard at first and last glance did not vary across Visit for either the ACCEL or PALM conditions.

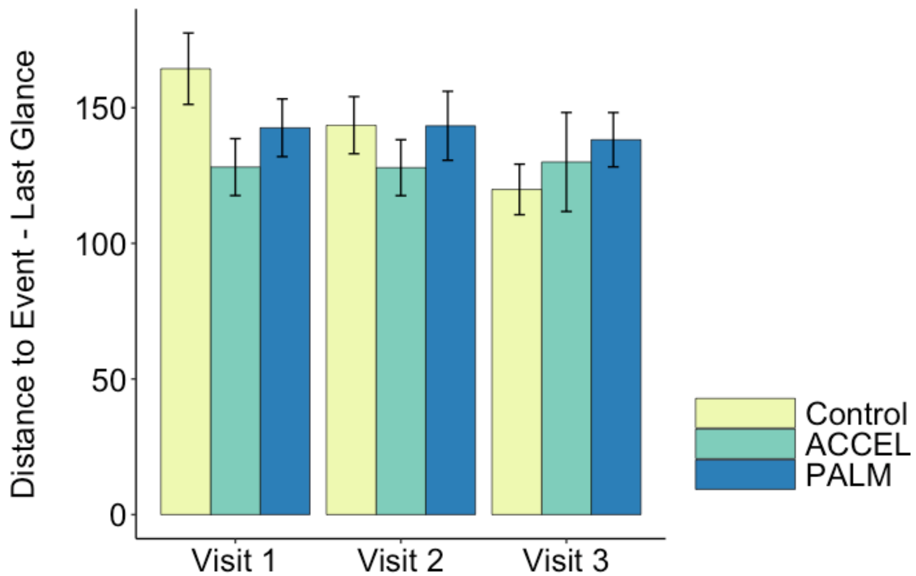

Figure 3.6 - Distance to the hazard at last glance for the obscured cross traffic lane

Table 3.3 - Model results predicting simulator performance and situation awareness from Condition and Visit for the obscured cross traffic lane

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Glance								
Distance to event at first glance	.10 [-.19, .40]	.24 [-.08, .55]	-.01 [-.30, .28]	.17 [-.14, .47]	**-.23** [-.45, -.02]	-.15 [-.35, .07]	-.08 [-.29, .14]	-.18 [-.40, .04]
Distance to event at last glance	.12 [-.22, .45]	.19 [-.17, .55]	.11 [-.23, .44]	.23 [-.11, .58]	**-.25^{+}** [-.49, -.004]	-.11 [-.35, .13]	-.11 [-.36, .13]	**-.27** [-.53, -.01]
Percentage of glance time during the entire event window	-.003 [-.05, .04]	.004 [-.05, .05]	-.01 [-.06, .04]	-.02 [-.07, .03]	.001 [-.04, .04]	.01 [-.03, .05]	.01 [-.02, .04]	.01 [-.03, .04]
Percentage of glance time during the close proximity period	.01 [-.05, .07]	-.03 [-.09, .03]	.003 [-.06, .06]	-.02 [-.08, .04]	.02 [-.02, .06]	.02 [-.02, .06]	.01 [-.03, .05]	.03 [-.01, .07]
Situational Awareness								
Maximum SA	-.06 [-.65, .53]	-.06 [-.79, .43]	-.47 [-1.07, .13]	-.35 [-.96, .27]	-.10 [-.36, .54]	.38 [-.09, .84]	.19 -.23, .61]	.15 [-.29, .59]

$^{+}$ $p \leq .08$

3.4 Potential vehicle incursion

Analysis of glance data to the event included measures of the time to first glance and percentage of the event window and close proximity period spent glancing to the hazard. Simulator measures included analyses of the minimum speed observed throughout the event window and whether or not the participant released the accelerator. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.4.

Analysis of the time it took participants to look at the hazard revealed a significant Condition x Visit interaction for those in the ACCEL condition compared to controls at visit 2 compared to visit 1(Figure 3.7). When examined within Condition, Visit did not significantly predict the time to first glance for those in the control, *b* = -.50, *t* (89.00) = -1.44, *ns, or* ACCEL conditions, *b* = .68, *t* (61.34) = 1.61, *ns*, at visit 1 compared to visit 2. The interaction, instead, seems to stem from differences between the two conditions at visit 1 (i.e., control glances at the event longer than ACCEL) and again at visit 2 (i.e., ACCEL glances at the event longer than control). Because our study aims to track differences over time, we chose not to examine the interaction within Visit. However, it is notable that, while not significant, those in the control condition trended toward glancing to the event sooner (by about .52 sec) at visit 2 than at visit 1, whereas those in the ACCEL condition trended toward glancing to the event later (by about .70 sec) at visit 2 compared to visit 1.

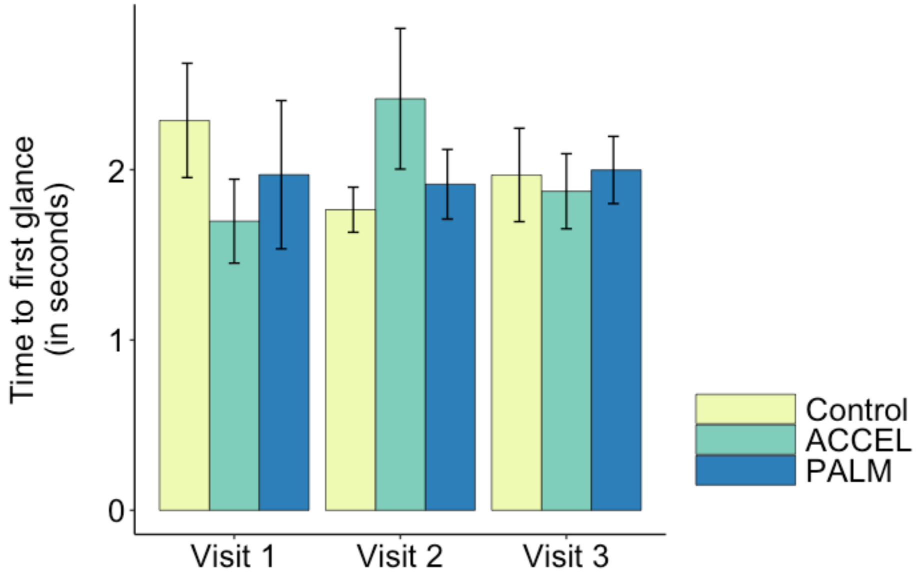

Figure 3.7. Time to first glance to the incursion vehicle by Condition and Visit

Linear regression models predicting the percentage of the event window spent glancing to the hazard did not reveal main effects of Condition, Visit, or their interactions. Similarly, the models predicting the percentage of the close proximity period spent glancing to the hazard did not reveal main effects of Condition, Visit, or their interactions.

Analysis of minimum speed revealed a marginally significant Condition x Visit interaction when comparing those in the PALM to Controls at visit 2 compared to visit 1 (Figure 3.8**Error! Reference source not found.**). When examined within Condition, Visit predicted a marginally significant .98 mph increase in minimum speed at visit 2 compared to visit 1 for those in the control condition, *b* = .98, *t* = 2.00, *p* = .05, whereas Visit did not predict minimum speed for those in the PALM condition, *b* = -.56, *t* = -.88, *ns*.

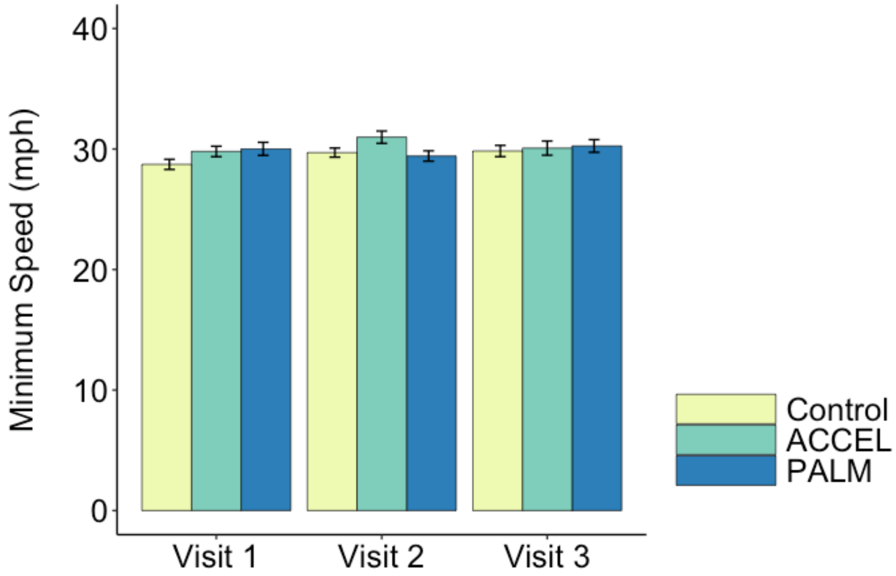

Figure 3.8 – Minimum speed during the potential incursion event

The logistic regression model predicting whether or not participants released the accelerator in response to the hazard did not reveal significant effects of Condition, Visit, or their interactions. Distance to the hazard at accelerator release was not considered, as the number of accelerator releases was not sufficient to examine the interaction of Condition and Visit.

The potential vehicle incursion event was selected from the PALM training but was also related to concepts in the ACCEL training. There were no notable effects across visits for those in the PALM condition and those in the ACCEL group took marginally longer to look at the hazard at visit 2 compared to visit 1. The control group looked at the hazard marginally sooner and traveled through the event with a slightly higher minimum speed at visit 2.

Table 3.4 - Model results predicting glance and simulator performance from Condition and Visit for the potential incursion vehicle

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Glance								
Time to first glance	**1.18** [.12, 2.24]	.47 [-.66, 1.60]	.43 [-.67, 1.52]	.39 [-.75, 1.51]	-.56 [-1.31, .19]	-.30 [-1.09, .49]	-.50 [-1.26, .24]	-.31 [-1.12, .49]
Percentage of glance time during the entire event window	-.04 [-.14, .06]	-.02 [-.12, .09]	.01 [-.09, .11]	.04 [-.06, .14]	.03 [-.04, .10]	-.02 [-.09, .06]	-.06 [-.12, .01]	-.06 [-.14, .01]
Percentage of glance time during the close proximity period	-.04 [-.14, .06]	-.02 [-.13, .09]	.02 [-.09, .12]	.05 [-.06, .16]	.04 [-.04, .11]	-.02 [-.10, .07]	-.06 [-.14, .01]	-.06 [-.15, .01]
Simulator								
Minimum speed	.21 [-1.37, 1.80]	-.80 [-2.49, .89]	**-1.56**+ [-3.15, .03]	-.85 [-2.55, .84]	1.09 [-.18, 2.36]	1.28 [-.01, 2.58]	.98 [-.13, 2.08]	1.16 [-0.04, 2.37]
Accelerator release	.37 [-.52, 1.26]	.36 [-.71, 1.42]	-.11 [-1.09, .86]	-.67 [-1.64, .30]	-.31 [-.93, .31]	.05 [-.53, .63]	-.26 [-.88, .37]	-.01 [-.76, .74]

+ $p \leq .08$

3.5 Partial lane obstruction

Analysis of the partial lane obstruction event included simulator measures of minimum speed and the distance to the hazard at the moment the participant shifted left in the lane. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.5.

Condition, Visit, and their interactions did not predict participants' minimum speed in response to the partial lane obstruction. The distance to the vehicle when participants shifted in the lane revealed a significant Condition x Visit interaction for ACCEL at visit 3. When examined within Condition, participants in the ACCEL condition shifted in the lane at a greater distance from the hazard at visit 3 compared to visit 1, $b = .28$, $t\,(61.32) = 2.08$, $p = .04$. Visit did not predict lane shift for controls, $b = -.12$, $t\,(64.67) = -.89$, *ns.* Participants in the ACCEL condition, on average, shifted left for the stopped vehicle at a distance of 182.73 ft at visit 3 compared to a distance of 147.31 ft for visit 1. The distance at which the control participants shifted decreased but was not significantly different at visit 3 than at visit 1. There was similar trend when comparing the PALM and control condition at visit 2 when compared to visit 1. While not statistically significant, those in the PALM condition shifted in the lane at a further distance to the event at visit 2.

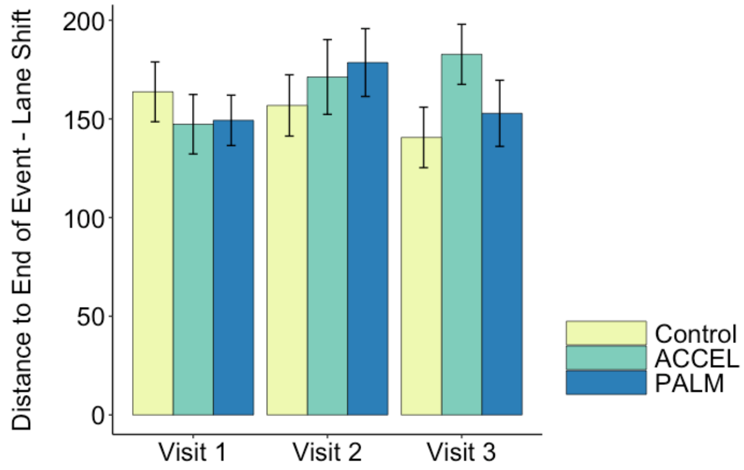

Figure 3.9 - Distance to the end of the partial lane obstruction when participant shifted in the lane by Condition and Visit

3.6 Dynamic object

Analysis of the dynamic object hazard was conducted to determine the effect of Condition and Visit on participants' minimum speed. As with the partial lane obstruction, we considered including the distance to the hazard when the participant shifted left in the lane. However, there were too few lane shift responses to support analysis. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.6.

The model predicting minimum speed during the dynamic object event did not show significant effects of Condition, Visit, or their interactions.

Table 3.5 - Model results predicting simulator performance from Condition and Visit for the partial lane obstruction

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Simulator								
Minimum Speed	0.42 [-3.24, 4.07]	-.09 [-3.99, 3.81]	1.14 [-2.50, 4.78]	1.07 [-2.83, 4.97]	1.66 [-1.19, 4.51]	.77 [-2.12, 3.66]	1.24 [-1.29, 3.78]	.48 [-2.31, 3.27]
Distance to event at lane shift	.21 [-.15, .56]	**.41** [.03, .79]	.28 [-.08, .63]	.04 [-.34, .42]	-.15 [-.42, .11]	-.08 [-.35, .18]	-.12 [-.36, .13]	-.13 [-.40, .14]

Table 3.6 - Model results predicting simulator performance from Condition and Visit for the dynamic object event

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Simulator								
Minimum speed	1.03 [-2.86, 4.91]	.50 [-3.59, 4.60]	1.41 [-2.49, 5.30]	2.87 [-1.25, 6.99]	.80 [-1.92, 3.52]	-.87 [-3.66, 1.91]	-.73 [-3.44, 1.99]	-.58 [-3.51, 2.35]

3.7 Work zone lane closure

Analysis of the work zone lane closure event was limited to the simulator measure of distance to the start of the work zone at time of lane change. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.7.This measure did not vary systematically by Condition, Visit, or their interactions.

3.8 Lane drop

Only the simulator measure of distance to the end of the transition at time of lane change was considered for the lane drop. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.8.

Analysis revealed a marginal Condition x Visit interaction for those in the ACCEL condition compared to control (**Error! Reference source not found.**). When examined by Condition, Visit predicted the lane change distance at visit 2 compared to visit 1 for controls, b = .33, t (43.9) = 2.64, p = .01. Visit did not predict the distance to the transition when participants changed lanes for those in the ACCEL condition, b = -.02, t (42.03) = -.15, *ns.* Additionally, there was a significant main effect of Visit such that participants changed lanes an average of 49 ft earlier at visit 2 and an average of 144 ft earlier at visit 3 compared to visit 1.

The lane drop event represented hazard training from both the ACCEL and PALM programs. Results indicate that participants in the control condition changed lanes earlier at visit 2 than at visit 1, whereas those in the ACCEL condition did not show a significant change. The main effect of Visit indicates an effect of experience, but it is not possible to determine whether this is due to repeated experience with this event in the study drives, real world driving experience, or a combination of both.

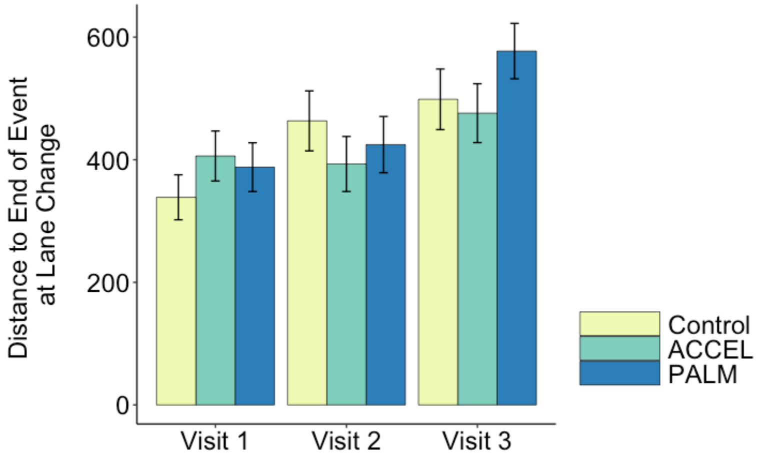

Figure 3.10 - Distance to the end of the transition at lane change for the lane drop by Condition and Visit

Table 3.7 - Model results predicting simulator performance from Condition and Visit for the work zone lane closure

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Simulator								
Distance to event at lane change	.02 [-.24, .29]	-.03 [-.12, .42]	.15 [-.32, .26]	.24 [-.04, .54]	.04 [-.20, .27]	-.16 [-.40, .08]	.10 [-.08, .29]	.17 [-.04, .38]

Table 3.8 - Model results predicting simulator performance from Condition and Visit for the lane drop

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Simulator								
Distance to event at lane change	**-.34**[+] [-.72, .04]	-.17 [-.57, .23]	-.26 [-.63, .10]	.03 [-.34, .40]	.17 [-.15, .50]	.14 [-.18, .47]	**.34** [.07, .60]	**.44** [.17, .72]

+ p ≤ .08

3.9 90-degree curve

For the curve event, simulator measures considered were minimum speed, the distance from the start of the event window at which the accelerator was released, and the distance from the start of the event window at which the brake was pressed. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.9**Error! Reference source not found.**.

Models predicting minimum speed revealed main effects of Visit. Minimum speeds through the curve event were significantly lower during visit 1 than at visits 2 and 3 (Figure 3.11), with participants travelling 1.25 and 1.54 mph faster at visit 2 and 3, respectively. Neither Condition nor its interaction with Visit reached significance.

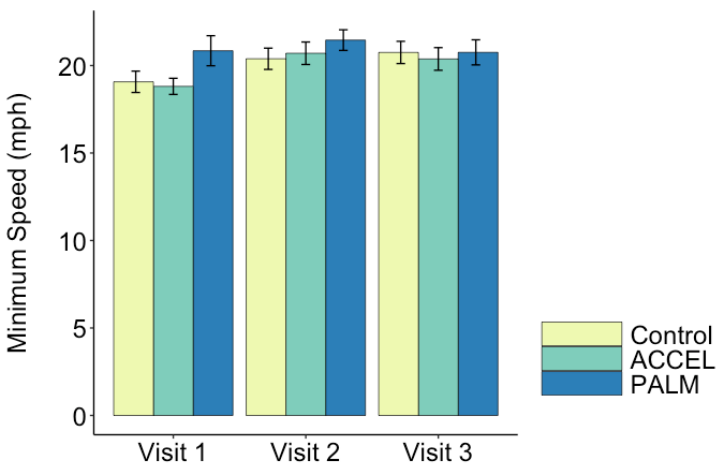

Figure 3.11 - Minimum speed for the curve event by Condition and Visit

Accelerator release distance was not predicted by Condition, Visit, or their interaction. Analysis of the brake release distance from the start of the event revealed a significant Condition x Visit interaction for those in the ACCEL condition compared to controls at visit 3 verses visit 1 (Figure 3.12). When examined within Condition, Visit predicted the distance from the start when the brake was pressed for controls, *b* = .69, *t*

(40.05) = 3.37, $p < .001$, but not for those in the ACCEL condition, $b = -.15$, t (33.13) = -.28, *ns*. Participants in the control condition braked significantly later at visit 3 than they did at visit 1.

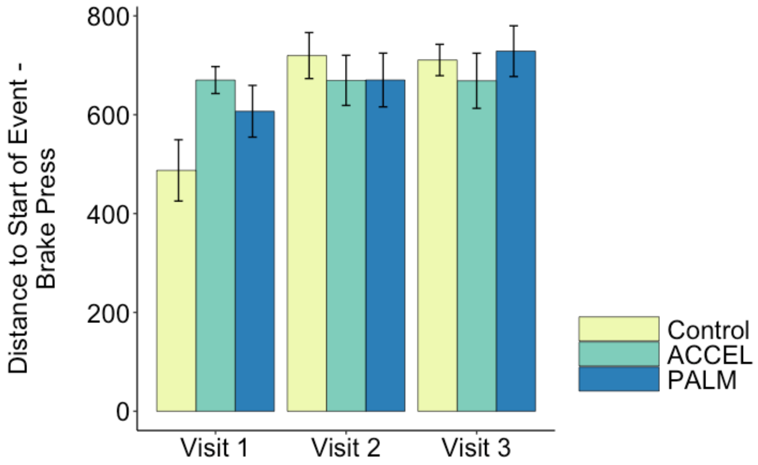

Figure 3.12 - Distance from the start of the curve event at brake press by Condition and Visit

The curve event was included as a direct representation of a concept covered by the ACCEL training condition. Despite the curve event being directly represented in the ACCEL training, there did not seem to be an effect of the ACCEL training on the measures examined here.

Table 3.9 - Model results predicting simulator performance from Condition and Visit for the curve event

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Simulator								
Minimum speed	.59 [-1.15, 2.34]	-.47 [-2.06, 1.72]	-.17 [-2.28, 1.32]	-1.57 [-3.48, .32]	-.27 [-1.95, 1.40]	1.58 [-.15, 3.30]	**1.25** [.03, 2.46]	**1.55** [.21, 2.88]
Distance to event – accelerator release	-.20 [-.87, .47]	.15 [-.54, .85]	-.21 [-.90, .47]	.30 [-.41, 1.01]	-.34 [-.85, .16]	-.07 [-.59, .44]	.15 [-.32, .61]	.07 [-.42, .56]
Distance to event – brake press	-.89 [-2.08, .30]	**-1.31** [-2.48, -.13]	-.92 [-2.10, .27]	-.35 [-1.55, .85]	.64 [-.26, 1.53]	.29 [-.61, 1.19]	.70 [-.07, 1.47]	.71 [-1.55, .85]

3.10 Platoon braking

Both glance and simulator measures were considered for the platoon braking event. Given the complexity of the event, we considered glance measures across entirety of the event window as well as just after the first and second braking events. Glance measures included the time to first glance as well as the percentage of time spend glancing to the hazard over the entire event window, between the first and second braking events and after the third braking event.

Analysis of the time to first glance did not reveal significant effects of Condition, Visit, or their interactions; nor did the models predicting the percentage of time spend glancing at the hazard over the entire event window, after the first braking event, or after the second braking event.

3.11 School Zone

Analysis of the school zone included the simulator measure of minimum speed. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions are shown in Table 3.11.

The model predicting minimum speed did not reveal main effects of Condition, Visit, or their interaction.

Table 3.10 - Model results predicting simulator performance from Condition and Visit for the platoon braking event

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Glance								
Full event								
Time to first glance	.11 [-.74, .51]	-.39 [-1.05, .27]	-.55 [-1.19, .08]	-.40 [-1.05, .26]	.08 [-.37, .53]	.40 [-.06, .85]	.24 [-.21, .68]	.23 [-.24, .69]
Percentage of glance time	.01 [-.09, .11]	.03 [-.08, .13]	-.03 [-.13, .07]	-.02 [-.08, .13]	-.02 [-.10, .06]	-.02 [-.10, .06]	.02 [-.05, .09]	.03 [-.05, .10]
After first braking event								
Percentage of glance time	.01 [-.12, .13]	.02 [-.11, .16]	-.04 [-.17, .08]	-.07 [-.20, .07]	-.03 [-.13, .06]	-.02 [-.11, .08]	.01 [-.08, .10]	.05 [-.05, .14]
After second braking event								
Percentage of glance time	.03 [-.09, .15]	.03 [-.10, .16]	-.05 [-.17, .07]	-.04 [-.17, .09]	-.03 [-.12, .06]	.02 [-.08, .12]	.03 [-.06, .11]	.03 [-.07, .12]

Table 3.11 - Model results predicting simulator performance from Condition and Visit for the school zone event

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Simulator								
Minimum speed	.97 [-1.43, 3.38]	.38 [-2.14, 2.91]	.12 [-2.28, 2.53]	-.82 [-3.35, 1.72]	-1.25 [-2.95, .45]	-.12 [-1.84, 1.59]	-.04 [-1.71, 1.63]	.51 [-1.29, 2.31]

3.12 Secondary tasks

Both glance and simulator measures were considered for the secondary tasks and are organized by the location of the event (urban or rural). However, glance data was only considered for the dialing task completed in the urban area of the drive. The glance measure for this event included an analysis of the proportion of glances away from the roadway for a duration longer than two seconds. Simulator measures of standard deviation of speed and standard deviation of lane position were considered separately for the urban and rural secondary tasks. For both the urban and rural areas, the dialing and contact search tasks were combined for analysis. Beta estimates and 95% confidence intervals for main effects as well as the Condition x Visit interactions can be found in Table 3.12.

3.12.1 Urban

Analysis of whether or not participants looked away from the roadway for a duration lasting longer than two seconds did not reveal main effects of condition, visit, or their interactions (Figure 3.13).

For the urban secondary tasks, standard deviation of speed was associated with Visit. Compared to visit 1, visit 2 predicted a marginal reduction in standard deviation of speed and visit 3 predicted a significant reduction in standard deviation of speed (Figure 3.14). No effect of Condition or its interaction with Visit emerged.

Similarly, compared to visit 1, visit 2 predicted a marginal reduction and visit 3 predicted a significant reduction in standard deviation of lateral lane position for the urban secondary tasks (Figure 3.15). Condition marginally predicted a reduction in standard deviation of lane position for controls compared to those in the PALM condition.

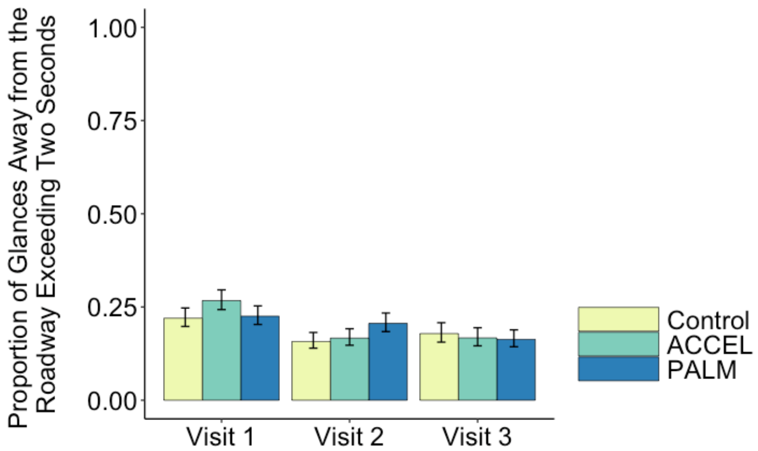

Figure 3.13 - Proportion of glances exceeding two seconds during the urban dialing task

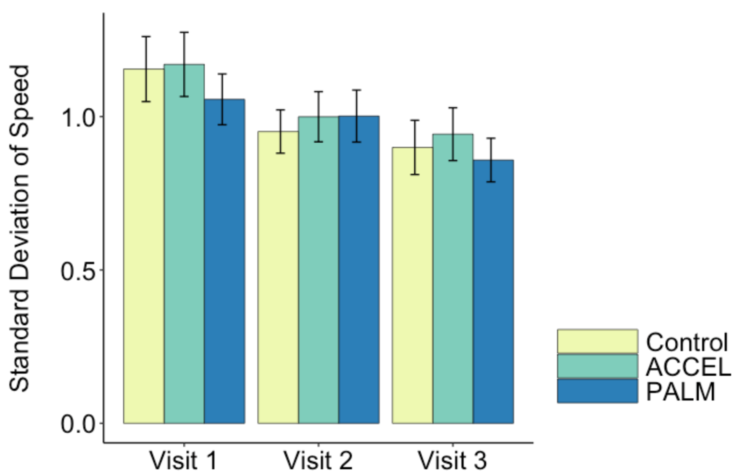

Figure 3.14 - Standard deviation of speed during the urban secondary tasks

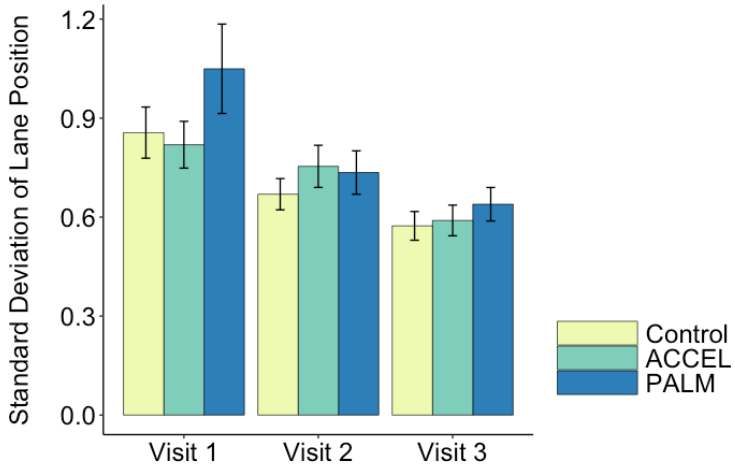

Figure 3.15 - Standard deviation of lane position during the urban secondary tasks

3.12.2 Rural

For the rural secondary tasks, Visit predicted standard deviation of speed such that participants were significantly less variable at visit 3 compared to visit 1 (Figure 3.16). Neither Condition nor its interaction with Visit were significant.

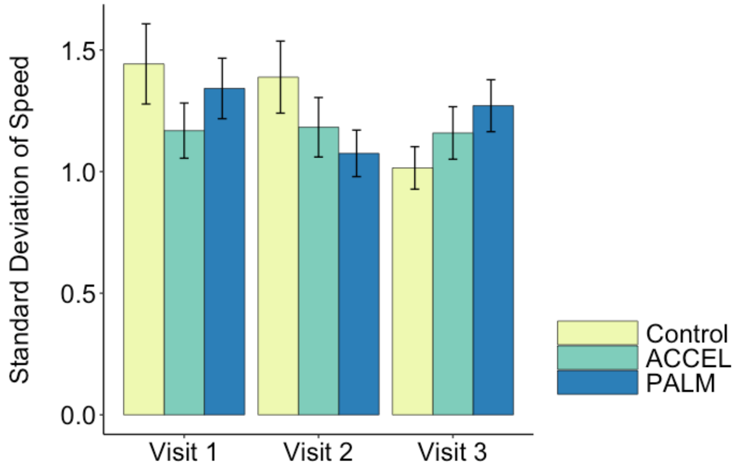

Figure 3.16 - Standard deviation of speed during the rural secondary tasks

Unlike the urban area, a marginal Condition x Visit interaction emerged for those in the ACCEL compared to controls at visit 3 compared to visit 1 for standard deviation of speed (Figure 3.17). When examined by Condition, Visit predicted a significant reduction in standard deviation of lane position, *b* = -.26, *t* (179.67) = -2.37, *p* = .02, for control, but not for those in the ACCEL condition, *b* = .04, *t* (173.52) = .39, *ns.* Additionally, Visit predicted a reduction in standard of lane position deviation at visit 3 compared to visit 1. Condition also predicted standard deviation of lane position such that those in the PALM condition were more variable than controls.

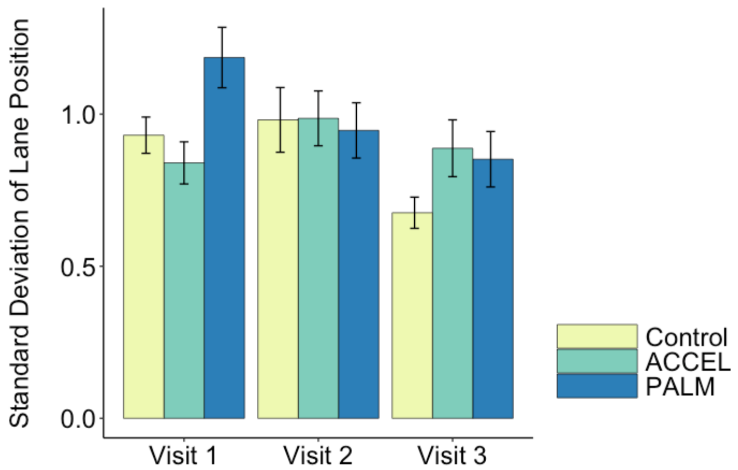

Figure 3.17 - Standard deviation of lane position during the rural secondary tasks

The secondary tasks were included for the purpose of examining attention maintenance - a skill included in the ACCEL training. Despite direct training of this skill in the ACCEL program, these participants performed no differently at visit 2 than those on the control condition. Rather, increased experience predicted decreases in variability of both speed and lane position in the urban and rural secondary tasks, especially for visit 3.

Table 3.12 - Model results predicting simulator performance from Condition and Visit for the urban and rural secondary tasks

	Condition x Visit Interactions				Main Effects			
	ACCEL vs Control		PALM vs Control		Condition		Visit	
Measures *b* 95% CI [UL, LL]	Visit 2	Visit 3	Visit 2	Visit 3	ACCEL	PALM	Visit 2	Visit 3
Glance								
Urban Dialing	.02 [-.41, .46]	-.26 [-.73, .20]	.29 [-.15, .73]	-.13 [-.60, .33]	.18 [-.16, .52]	.01 [-.34, .36]	-.26 [-.58, .05]	-.08 [-.41, .26]
Simulator								
Urban								
SD – speed	.05 [-.27, .36]	.03 [-.30, .37]	.16 [-.15, .47]	.06 [-.27, .40]	.02 [-.23, .26]	-.09 [-.34, .16]	**-.20⁺** [-.42, .01]	**-.26** [-.50, -.02]
SD – lane position	.12 [-.16, .39]	.05 [-.24, .34]	-.13, [-.41, .14]	-.13 [-.42, .16]	-.03 [-.23, .16]	**.20** [.00, .40]	**-.19⁺** [-.38, .00]	**-.28** [-.48, -.07]
Rural								
SD – speed	.06 [-.39, .51]	.37 [-.10, .84]	-.22 [-.66, .22]	.32 [-.15, .80]	-.26 [-.61, .08]	-.08 [-.43, .27]	-.05 [-.36, .26]	**-.39** [-.73, -.06]
SD – lane position	.10 [-.21, .41]	**.32⁺** [-.01, .64]	**-.29** [-.60, .02]	-.07 [-.40, .26]	-.09 [-.33, .15]	**.24** [.00, .49]	-.05 [-.16, .27]	**-.27** [-.50, -.03]

⁺ $p \leq .08$

4 Discussion and Conclusions

This research study aimed to evaluate the whether the Perceptual Adaptive Learning Module (PALM) and Accelerated Curriculum to Create Effective Learning (ACCEL) driver training programs affected novice teen drivers' ability to detect, monitor, and respond to potential hazards during simulated driving. More specifically, this longitudinal study sought to determine the impact of training as compared to the hazard anticipation skills that novice drivers acquire over time with driving experience.

Participants took part in three study visits over the course of six months: pre-test, post-test, and follow-up. Potential hazard events represented in the training programs were selected for inclusion on the three study drives that were counterbalanced by study visit. Within each drive, the same set of potential hazards were presented in different sequences and locations. Participants were drivers ages 15 and 16 years, and the first study visit occurred within two weeks of receiving driver's license that allowed independent driving without adult supervision. At pre-test, all participants completed a baseline simulator drive. Upon completion of the baseline drive, participants learned which condition they had been randomly assigned to: PALM training, ACCEL training, or Control. Those assigned to a training condition completed the respective program immediately. After 6 weeks of independent driving experience, participants completed a post-test simulator drive. Finally, participants returned for a final follow-up simulator drive after 24 weeks of driving experience, which is the focus of this Safer-Sim effort.

Generally, the analysis of driver attention and driving mitigation of potential hazards reveled few significant differences among the training and control conditions. While not evident across all events, there did seem to be a positive impact of the ACCEL training with respect to some of the events examined. For instance, there was evidence of improvement in participants' driving mitigation, with participants in the ACCEL condition shifting in the lane sooner at the visit 3 follow-up than at the visit 1 pre-test when presented with a partially obstructed lane. Additionally, those in the ACCEL condition attained a higher level of situational awareness during the parallel parked car event at the visit 2 post-test compared to visit 1. However, situation awareness for this event was somewhat lower at the visit 3 follow-up and not significantly higher than the visit 1 pre-test. There was also a trend for those in the ACCEL training group to spend a larger proportion of time glancing to the parallel parked car at the visit 2 post-test, six weeks after training, than at the first visit. While this effect did not reach statistical significance, it may indicate that the training contributed to improved monitoring of potential roadway hazards.

Together, these results suggest that the ACCEL training may have a net benefit in helping teens identify, monitor, and mitigate potential hazards. However, these effects were only present for a small number of the events analyzed here. Predecessors of the ACCEL training (e.g., Risk Awareness and Perception Training; RAPT) have also failed to show consistent effects of the training on hazard anticipation as compared to a control condition. Notably, a study of RAPT administered to newly-licensed drivers in California did not show a benefit of the training with regard to crash rates and traffic violations generally, but crash rates were significantly lower for males in the study [19]. One aspect of the ACCEL training that sets it apart from prior, related training programs like RAPT is the added components of hazard mitigation and attention maintenance. Indeed, the first evaluation of ACCEL hypothesized this was the reason the RAPT evaluation did not show a significant benefit for females and reported that there were no gender differences in training effects for ACCEL [16]. While our results show some support for the benefit of the mitigation portion of the training, attention maintenance did not show improvement from baseline to subsequent visits to relative to controls. Specifically, when analyzing the urban phone dialing task, participants in the ACCEL condition did not differ from controls in the proportion of glances away from the roadway that lasted longer than two seconds. This conflicts with a driving simulator study of the SAFE-T program – another variant of the ACCEL program – which found that SAFE-T trained participants had about 12% fewer glances longer than 2 seconds during various secondary tasks [20]. Importantly, participants in the SAFE-T study had two years of driving experience at the time of participation, whereas the participants in the current study had accumulated very little if any independent driving experience. It could be the case that training in attention maintenance works best for those who already have independent driving experience and have had the opportunity to develop other driving skills.

As with the ACCEL training condition, there were limited significant results associated with the PALM training compared to the control condition. Those in the PALM training also showed a significant improvement in the distance at which they shifted in the lane in response to the partial lane obstruction and in situational awareness level for the parallel parked car as compared to controls. There was a trend for those in the PALM training program to spend a larger proportion of time glancing to the parallel parked car at the visit 2 post-test than at visit 1, though this effect did not persist for visit 3. Together, this indicates that the PALM training may also be effective at helping novice drivers identify, monitor, and respond to hazards that may impact forward travel. Both the parallel parked car and the partial lane obstruction were directly represented in the PALM training which may help explain why participants showed improvements at visit 2. However, this and other PALM training programs are designed to generalize more broadly to the topic of the training. For example, PALM trainings designed to aid medical students in diagnosis using electrocardiography and histopathology showed a robust benefit of the training [21].

While the training programs did seem to accelerate hazard anticipation and mitigation for a small number of hazard of events, the role of driving experience was also evident. From baseline to post-test, there were improvements in the distance at which all participants changed lanes in response to the lane drop, as well as reductions in variability of speed and lane position when engaged in the secondary tasks. There was also an effect of visit from baseline to follow-up with participants in all conditions looking at the parallel parked car for a greater proportion of time after 24 weeks of driving compared to the first visit. However, it is unclear if these improvements are related to experience gained from on-road, unsupervised driving or because of previous study drive experience(s) in the driving simulator.

There were a number of limitations to the present study that may have hindered our ability to detect more robust effects of the training programs. The performance of participants in the simulator drives was highly variable, particularly at visit 1, which likely made finding differences of condition and experience difficult. Additionally, we encountered several unexpected difficulties regarding the eye tracker and related software. More specifically, we are unable to use automatic glance analysis in the DLab software due to the dynamic environment. As a result, manual coding of eye data was required, and the time and resources available for this effort were limited. Finally, our measure of situational awareness, adapted from the approach outlined by Katrahmani and colleagues [2], only detected effect of training for a single event. In addition, for the mid-block crosswalk we observed a ceiling effect at visit 1. This may indicate the need to adjust the situation awareness framework for complex hazard situations, especially when events have multiple cues and areas from where hazards could materialize. Further, future analysis of these data may consider examining the effects of condition and experience across events, rather than examining each event separately.

In conclusion, both programs seem to have some limited benefit in improving hazard anticipation and mitigation. These effects seemed most pronounced for events involving objects that may move into the lane ahead of the driver. For the PALM, these improvements seemed to be related to events that were directly represented in the training. It may also be the case that, despite the methodological strength of the study design, we were unable to detect effects due 1) a large amount of variability among newly licensed drivers and 2) to an inability to determine if a glance to a hazard conveys perception of that hazard as such. Situational awareness coding was beneficial in determining the impacts of the training on both hazard anticipation and mitigation and will be explored further in future efforts.

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Appendix A: Enrollment and Study Completion by Gender

Table 4.1 - Enrollment and study completion by Condition and License type for Females

		Completed Visits			Completed Visits with Eye Data	
	Enrolled	Visit 1	Visit 2	Visit 3	Visit 2	Visit 3
ACCEL	27	24	18	17	18	17
MSL	16	16	12	11	12	11
INT	11	8	6	6	6	6
PALM	27	22	19	16	19	16
MSL	16	13	13	10	13	10
INT	11	9	6	6	6	6
Control	25	23	18	14	18	14
MSL	15	15	12	9	12	9
INT	10	8	6	5	6	5
Total	79	69	55	47	55	47
MSL	47	44	37	30	37	30
INT	32	25	18	17	18	17

Table 4.2 - Enrollment and study completion by Condition and License type for Males

		Completed Visits			Completed Visits with Eye Data	
	Enrolled	Visit 1	Visit 2	Visit 3	Visit 2	Visit 3
ACCEL	20	19	17	14	16	13
MSL	11	10	9	8	9	8
INT	9	9	8	6	7	5
PALM	19	18	16	14	15	14
MSL	12	11	10	8	9	8
INT	7	7	6	6	6	6
Control	23	22	20	15	17	15
MSL	13	13	12	9	10	9
INT	10	9	8	6	7	6
Total	62	59	53	43	48	42
MSL	36	34	31	25	28	25
INT	26	25	22	18	20	17

Appendix B: Mileage Log

At the conclusion of the first visit, participants were given instructions on how to report information related to their driving including: their general destinations, conditions in which they drive, and the number of miles driven according to their odometer reading. They were provided with a log to help them track this information (Figure 4.1). The log also provided participants with a field in which other drivers of the vehicle could enter their miles driven in cases where there were multiple users of the same vehicle. Participants submitted the information from the mileage log once per week via Qualtrics survey.

Subject ID: **Start date:** **End date:**

Starting odometer reading	Ending odometer reading

	Trip destination		Driving Conditions				
	School/ Home	Other	Night	Heavy Traffic	Divided Highway or Interstate	2-lane road 55 MPH+	Inclement weather
Sunday							
Monday							
Tuesday							
Wednesday							
Thursday							
Friday							
Saturday							

Other Drivers

	Date	Miles driven		Date	Miles driven		Date	Miles driven	
1			7			13			
2			8			14			
3			9			15			
4			10			16			
5			11			17			**Total**
6			12			18			

Figure 4.1 - Mileage Log