2014

Investigating Teenage Drivers' Driving Behavior before and after LAG (Less Aggressive Goals) Training Program

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INVESTIGATING TEENAGE DRIVERS' DRIVING BEHAVIOR BEFORE AND

AFTER LAG (LESS AGGRESSIVE GOALS) TRAINING PROGRAM

A Thesis Presented

By

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Submitted to the Graduate School of the

University of Massachusetts Amherst in partial fulfillment

of the requirements for the degree of

MASTER OF SCIENCE IN INDUSTRIAL ENGINEERING AND OPERATION

RESEARCH

SEPTEMBER 2014

Mechanical and Industrial Engineering

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ACKNOWLEDGEMENTS

ABSTRACT

INVESTIGATING TEENAGE DRIVERS DRIVING BEHAVIOR BEFORE AND

AFTER AGGRESSIVE TRAINING PROGRAM

SEPTEMBER 2014

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Motor vehicle crashes are a leading cause of death during adolescence, with the fatal crash rate per mile-driven for 16-19 years old drivers being nearly 3 times larger than the rate for drivers age 20 and older (IIHS, 2010). High gravitational events among teenage drivers, such as quick starts, and hard stops, have been shown to be highly correlated with crash rates (Simons-Morton et al., 2012). The current younger driver training programs developed in the late 1990s, however, do not appear to be especially effective in regard to many skills which are critical to avoiding crashes (IIHS, 2004). With this in mind, a simulator-based training program aimed at reducing the behaviors that make quick accelerations unsafe and quick decelerations unnecessary was designed and evaluated. The training adopts the active training strategy which has been proven to be effective, and includes those scenarios in which teenage drivers are at highest risks. It

is expected that drivers who receive the active training will drive more safely than drivers who receive the placebo training, in terms of eye scanning behaviors in scenarios where quick accelerations are necessary (e.g., how often they glance towards areas where threats could emerge), following behaviors in scenarios where a lead vehicle could stop suddenly (e.g., how much headway they allow between their vehicle and a lead vehicle), and vehicle behaviors such as speed, acceleration rate, deceleration rate and headway.

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CHAPTER 1

INTRODUCTION

Motor vehicle crashes are the leading cause of death during adolescence. In the United States in 2009, the latest year for which data is available, the number of deaths among 13-19 year-old males and females due to motor vehicle crashes was 3,487, compared with homicide (2,027) and suicide (1,852) (National Center for Injury Prevention and Control, 2012). Inexperienced young drivers, especially during the first year of independent driving after being licensed, are at a relatively high risk for crashes, injury and death. In the United States, the fatal crash rate per mile driven for 16-19 year-olds is nearly 3 times the rate for drivers ages 20 and over (IIHS, 2010). In 1995 in the United States, sixteen year-old drivers were involved in 35 crashes per million miles of travel, compared to drivers in their 20s and early 40s who were involved in 9 and 4 crashes, respectively, per million miles (Williams, 1995).

Near-crash rates, at the same time, were higher for teenage than adult drivers as well (Klauer et al., 2009; Guo et al., 2010). Near-crashes are treated as an index of risky driving since a near-crash, by definition, requires a successful, last-second evasive maneuver in order to avoid a crash (Lee et al., 2011). Though such data is not included in any fatal crash reports, near-crashes are a good index of crash risk since the mistakes leading to crashes will often be the same as those leading to near-crashes, the difference being only that due to luck, circumstance and/or the actions of other drivers, in one instance the crash occurred and in another it was avoided.

The focus of this thesis is on teenagers' aggressive driving behaviors, especially such drivers' acceleration and deceleration behaviors. Previous studies have identified a number of behaviors that could decrease teenagers' crash risk, including increasing seat-belt use among drivers and passengers (e.g., Briggs et al., 2008; Goodwin and Foss, 2004; Goodwin et al., 2006), restrictions on the number of passengers (e.g., Lee and Abdel-Aty, 2008; Neyens and Boyle, 2008; Preusser et al., 1998; Simons-Morton et al., 2005), night-time driving constraints (e.g., Lin and Fearn, 2003; Morrisey et al., 2006; Simons-Morton and Hartos, 2003), and restrictions on cell-phone use (e.g., Foss et al., 2009; Neyens and Boyle, 2008). Very little research has focused on how changes in teenagers' quick starting and quick stopping behaviors could potentially decrease their crash risk.

Quick acceleration and deceleration are considered aggressive maneuvers because they can increase the potential loss of vehicle control and reduce the time available for drivers to respond to hazards and for other road users to respond to the drivers' behavior (Bagdadi and Varhelyi, 2011; Elvik, 2006). Research has shown that teenage drivers have much higher rates of quick deceleration and acceleration per mile driven than experienced adult drivers (Romoser et al., 2012). While there are several potential causes of traffic crashes, a leading cause is aggressive driving, broadly defined as any deliberate unsafe driving behavior performed with "ill intention or disregard to safety" (Tasca, 2000; AAA Foundation for Traffic Safety, 2009; NHTSA 2009). A recent study by the American Automobile Association (AAA Foundation for Traffic Safety, 2009) estimated that 56% of the fatal crashes that occurred between 2003 and 2007 involved potentially aggressive driving behaviors.

Situations in which a quick deceleration could occur and lead to a crash include tailgating. Drivers may simply have allowed too little room to brake in time or may be distracted. However, the situation is not always clear cut. In heavy traffic the judgment of what is a safe time headway is not always easy. If the driver follows too closely, a crash is almost inevitable if the lead vehicle stops suddenly for no apparent reason. If the driver follows too far from the lead vehicle, some other driver is bound to cut in and reduce the following distance.

Situations in which a quick acceleration could occur and lead to a crash include intersections. The driver may be turning left at a signalized intersection and misjudge the speed of the traffic in the opposing lane across which he or she is turning, or may fail to glance at such traffic altogether. However, here again the situation is not clear cut. The cross traffic at the intersection may be relatively fast moving and dense. The driver may indeed need to accelerate quickly, but can do such safely only when he or she has taken a glance for approaching traffic on both sides.

Explanations of why teenage drivers are more likely to engage in aggressive driving behaviors include accounts based both on biology and driving experience. With respect to biology, a number of recent studies have shown that the frontal cortex, the area of the brain where risk judgments are made, does not fully develop until the early twenties (Weinberger et al., 2005; Dahl, 2008; Chein et al., 2011). With respect to driving experience, researchers have shown that teenage drivers are not aware of many hazards which more experienced drivers clearly both anticipate and mitigate (Borowsky, 2010; Lee, 2006; Pradhan et al., 2009).

The effect on crashes of a number of teenage driver training programs developed in the middle and late 1990s that were designed to reduce the above risky behaviors has been evaluated. In general, they do not appear to be especially effective (Insurance Institute of Highway Safety, 2004). Given the failure of training programs to reduce crashes, policy makers turned to changes in the licensure scheme. A Cochrane review has shown that specifically targeted intervention strategies, such as graduated licensing schemes, can be successful in reducing the risk of crashing in teenage population (Russell et al., 2011).

However, recent studies have suggested that teenage drivers are clueless, not careless (McKnight and McKnight, 2003). This, together with advances in technology, has suggested that education can play a considerable role in reducing crashes of teenage drivers. In fact, recent efforts to decrease the high risk behaviors such as failures to anticipate hazards (Pradhan et al., 2009), failures to maintain attention (Pradhan et al., 2011) and failures to mitigate hazards (Muttart, 2011) that lead to crashes have proven successful, both in the field and on a driving simulator. However, a large scale evaluation of the effects of these recent training programs on crashes has yet to be undertaken.

The question posed in thesis is whether a similar training program could reduce the high frequency of unsafe quick starts and unnecessary quick stops that are known to increase crash risk among teenage drivers. To be clear, unsafe quick accelerations are defined as ones where quick accelerations are required, but the driver fails to take appropriate glances to avoid potential threats. An example is a stop sign-controlled intersection with dense cross traffic where the driver enters traffic quickly without glancing appropriately to the sides. Unnecessary quick decelerations are defined as quick

decelerations which could have been avoided had the driver planned ahead. An example here is a driver who is tailgating too closely when the lead car brakes suddenly. The driver must decelerate quickly, but it would have been unnecessary had he or she not been tailgating.

To address this issue, I proposed to design a simulator-based training program with real time feedback that is aimed at reducing teenage aggressive driving behaviors, especially unsafe quick accelerations and unnecessary emergency braking. I used active training methods when designing the training program since they have proven more effective than passive training methods (Romoser and Fisher, 2009). An active training program typically includes three modules: a mistakes module (putting drivers in situations where they can make an error), a mitigation module (providing immediate feedback on mistakes and explaining to drivers how to avoid the mistakes), and a mastery module (providing drivers the opportunity to practice in hazardous scenarios how to avoid a crash).

To evaluate the effectiveness of the training program, I conducted a study on a driving simulator. Qualified participants' age ranged in age from 18-19 with less than two years of licensed driving experience. The specific focus on younger drivers is because young drivers are significantly more likely than adult drivers to engage in acts of unsafe or unnecessary aggressive driving behaviors (Simons-Morton et al., 2005).

Initially, the participants were asked to navigate through a virtual world. At various points during the drive, the virtual world was populated with scenarios in which the driver should give evidence of properly anticipating and mitigating a potential crash.

Half of the participants were then given active training, half placebo training. Finally, the participants were evaluated on the driving simulator a second time. Vehicle measures (velocity, acceleration rate, throttle position, brake position, time headway) and eye movements were recorded throughout the drives so that the effect of aggressive driver training program could be assessed.

The remainder of this thesis is organized as follows: First I did a detailed literature review on several key factors in the thesis, including the relationship between quick acceleration, quick deceleration and the crash risk; the approach to the training program; and the evaluation strategy of the training program. Next I described the methods of the training programs, the evaluation procedure of the training program, and presented results from the evaluation session. Finally, I discussed the results and how the results supported my hypotheses.

CHAPTER 2

LITERATURE REVIEW

2.1 Quick Acceleration, Deceleration And Crash Risk

Quick accelerations and decelerations are known to correlate with increases in crash risk. For example, Wahlberg (2007) observed bus drivers' daily driving behavior from August 2001 to March 2004. Wahlberg hypothesized that drivers' average acceleration rates and deceleration rates could be used to predict crashes. However, no attempt was made to verify this relation.

A recent naturalistic study conducted by Simons-Morton et al. (2012) has shown that there exists a strong correlation between high-magnitude gravitational force (high g-force) events and the crash rate. High g-force events included acceleration from late braking, rapid starts and sharp turns. In this article, the high g-force event rates were categorized into 5 levels (Table 1). Twenty-two females and twenty males (newly licensed Virginia teenagers with an average age of 16.4 years) and at least one of their parents were recruited for this study. A data recording system that received and stored data from accelerometers, a global positioning system and a video recorder were installed in the participants' vehicles. The data-collecting period lasted from June 2006 to September 2009, and the whole data set contained more than 68,000 trips with an average of 1,626 trips per subject. Results from this study indicated that the crash and near crash risk rate were higher for drivers with more high g-force events (odds ratio = 1.07, 95% confidence interval: 1.02, 1.12). Such results were consistent with previous analyses done

by Simons-Morton et al. (2011) as well, which have shown that the high g-force event rates of teenage drivers were 5 times higher than adults' rates and did not decline significantly over the first 18-month period after their licensure. Such results are also consistent the previous hypothesis suggested by Wahlberg (2007).

Category	Gravitational Force
Rapid Starts	> 0.05
Hard Stops	≤ -0.45
Hard Left Turns	≤ -0.05
Hard Right Turns	≥ 0.05
Yaw*	6 Degrees in 3 Seconds

Table 1. Gravitational Force Events Category
* "Yaw" is a measure of correction after a turn and is calculated as the delta-V (change in velocity) between an initial turn and the correction or swerve

Crash rates differ between genders. A study conducted by Hakamies-Blomqvist (1994) revealed that young male drivers had higher rates of drunk driving and at-fault collisions than young female drivers. The data used in this study were the detailed on-location crash reports of the Finnish Road Accident Investigation Teams organized by the Traffic Safety Committee of the Insurance Companies. Within the age group of 14-24, and 25-34, males had higher rates of alcohol-impaired driving than females. Male drivers were more often involved in at-fault collisions and single-vehicle accidents than female drivers. Such results are consistent with most of the studies that have been done in this field (Evans, 1991; McKenna et al., 1998; Fu and Wilmot, 2008). Having this concern in mind, gender was balanced within and between the training group and the placebo group in this study as much as possible.

The studies mentioned above have provided references that a training program of aggressive driving for teen drivers is necessary and expected to have a positive effect on reducing crash risk.

2.2 Vehicle Behavior Feedback And Drivers' Behavior

There are several studies that have investigated how capturing in-vehicle data and providing feedback to drivers affects their behaviors and how face-valid feedback is highly effective in making people more willing to change their own behavior.

For example, a study that was conducted by Toledo, Musicant and Lotan (2008) depicted that data monitored and provided by an in-vehicle data recorder (IVDR) system was able to effectively reduce drivers' risky behaviors and crash risk rate. In the study, the IVDR system collected information which included: (1) vehicle and driver identification, (2) trip start and end times, (3) the lateral and the longitudinal acceleration of the vehicle, (4) the vehicle speed, (5) the vehicle location by a GPS receiver, and (6) other additional engine parameters that might be obtained via a vehicle on-board diagnostics system. Drivers received information and feedback provided by the IVDR system. This information included braking, speeding maneuvers, speed management, and corner handling. Drivers were able access to the data by logging into a website provided by the experimenters. However, no real-time feedback was provided.

In order to evaluate the impact of the IVDR installation and feedback, the authors analyzed the crash rates in the periods before and after the exposure. The results showed a statistically significant reduction of 38% (p=0.018) in crash rates. The authors conducted another evaluation regarding the effect of the IVDR feedback over time. They

found that behavior changes resisted extinction and that the mean, median and 85% percentile of the risk indices remained at lower levels seven months after exposure. Here the individual risk index was defined as a numeric measure to indicate the driver's risk of becoming involved in car crashes over a given period of time.

Mcgehee et al. (2007) conducted another study which proved that an event-triggered video system, together with weekly graphical report feedback and video review, could reduce teens' unsafe driving behavior when the feedback and review was done alongside their parents. In the study, each participant's vehicle was equipped with an event-triggered video recording system, which was triggered when the accelerometer reached a certain threshold. The video record included the interval 10 seconds before the event and 10 seconds after the event. During a baseline period in which no feedback was given, behaviors such as quick starts, quick stops, speeding, late braking, sharp turns, and quick turns were recorded by the video system. After the baseline period, event feedback was provided to drivers in the form of a personalized report and video clips. Feedback was reviewed by both the teen drivers and their parents. Results of the study showed that over a period of nine months the video feedback and parental mentoring significantly decreased the number of safety-relevant events when compared to the baseline period, especially for events connected with turning and curve negotiation.

Both studies suggest that providing drivers with appropriate, understandable driving behavior data, as well as video feedback, should help them better understand what aggressive behaviors look like and how to mitigate these potential hazards.

2.3 Active Training, Error Learning and Assessment

2.3.1 Active Training and Error Learning

Several recent studies have shown that active training, in which drivers learn from mistakes they have made during the training and practice strategies to correct those mistakes, is more effective than the traditional, passive training method. These training studies were undertaken, in part, because of earlier studies which showed the novice drivers were more often clueless than careless and therefore training might have an important role to play in reducing crashes. Some of these earlier studies of the differences between novice and experienced drivers used actual police crash reports (e.g., McKnight and McKnight, 2003). Other studies used data collected on a driving simulator.

For example, one earlier study (Pradhan et al., 2005) completed on a driving simulator showed that novice drivers were much less likely to anticipate hazards than experienced drivers. A typical scenario developed in the study illustrated well the difference in behavior between novice and experienced drivers. In this scenario, a truck stopped on the side of the road in front of a marked midblock crosswalk in a suburban development. The driver could not see potential pedestrians crossing in front of the truck and therefore should both look to the right for a pedestrian and steer farther to the left as passing in front of the truck. The study reported that 9.5% of the novice drivers scanned in front of the stopped truck, as compared with 28.6% of the younger drivers (19-29 years old) and 57.1% of the older drivers (60 years old and older).

In order to avoid endangering either the driver or others on the road and at the same time effectively train the drivers, a PC-based training program was the most

obvious way to proceed. Pollatsek, Narayannaan, Pradhan and Fisher (2006) first developed such a PC-based training program targeted at Risk Awareness and Perception Training (RAPT). It was hypothesized that if novice drivers were clueless, not careless, then training should have an effect on novice drivers' ability to anticipate hazards. In the evaluation of the RAPT program, one group was given the PC-based RAPT program and then evaluated on a driving simulator immediately after they finished the training. The other group was evaluated on the driving simulator similarly as well but without receiving any training program. The RAPT program used plan views instead of perspective drawings or actual videos. The program contained four sections. (1) In the first practice section each participant was given three practice scenarios to illustrate how using a mouse to move two types of symbols, red circles and yellow ovals, to appropriate regions of the plan vies. The red circles were used to indicate what area of the roadway should be monitored for potential threats and were to be moved to the area on the plan view where that monitoring should occurred; the yellow ovals were used to indicate areas of importance that would be hidden from the participants driver's view and were to be moved appropriately on the plan view. (2) During the second, pretest section, all 10 training scenarios were given to each participant. All the scenarios were counterbalanced. The position of each yellow oval and red circle in the participant response screen was recorded and scored on the pretest scores. (3) During the third training section, the participant was shown for each training scenario three displays in sequence: one which indicated his or her responses (the positions on the plan view of the red circle and yellow oval), one which showed how the hazard was obstructed by the built and natural environment, and one which explained the correct answers. Additionally, at the end of the

third training section, the participant was given the questions associated with each scenario and feedback. (4) In the fourth, posttest section, all 10 training scenarios were presented. The participants' responses were recorded and scored. These scores were counted as posttest scores.

Participants were nearly twice as good at placing the red circles correctly after training, scoring 50% on average in the pretest and 91% on the posttest, which was significantly different (t(23)=12.9, p<.001). As for placing the yellow ovals, the posttest scores were about three times as good as the pretest scores, respectively 90% on the posttest, and 32% on the pretest. The difference was significant as well (t(23)=19.1, p<.001). Both results (difference in placing red circles scores and yellow ovals scores) were consistent all through the 10 scenarios.

Similarly, a simulator-based training program targeted at teen drivers aggressive driving behavior was developed. It is believed that by following the previous 3M – Mistake, Mitigation, Mastery – strategy, the training program would have a significant effect on reducing teen drivers aggressive driving behaviors.

2.3.2 Assessment of Training

Although the training program was evaluated above, there is no guarantee that it will generalize from the PC to the open road. Ideally, one would test it on the open road. Barring this, an evaluation on a driving simulator is appropriate. This is just what Pollatsek et al. (2006) did. Specifically, as mentioned before, participants were evaluated on a driving simulator immediately after they finished the training session on the PC. The test scenarios on the driving simulator included both scenarios that were similar to those

included in the training (*near transfer scenarios*) and scenarios that were not similar to those in the training to examine if the training (*far transfer scenarios*) could go beyond the specific training scenarios. A total of 16 scenarios were included in the simulator evaluation, 10 near transfer scenarios and 6 far transfer scenarios. Vehicle data and participants' eye movements were collected and analyzed. Each scenario was scored either 1 or 0 depending on whether or not the participant's fixation pattern indicated recognition of risk as defined by the scoring criteria.

When gender was included in the analysis, the results from the study showed a significant effect of training if near and far transfer scenarios were analyzed together $F_{(1, 44)}= 23.91$, $p<.001$. Taking the gender out of the analysis, the effect of training is still significantly different, $F_{(1,46)}= 21.2$, $p<.001$, with trained driver recognizing risks 57.7% of the time and untrained 35.4% of the time. If the two sets of scenarios (near and far) are considered separately, the significance of the training still existed. For near transfer scenarios, 51.9% of the trained novice drivers recognized the risks, compared with 27.3% of the untrained novice drivers, $t_{(46)}=4.85$, $p<.001$. For far transfer scenarios, there was a significant difference of twenty percentage points between trained and untrained novice drivers, $t_{(46)}=3.27$, $p<.002$.

In all, the training program was shown to be effective. Participants' ability to diagnose risky situations and to anticipate potential hazards, which were the skills that such a training program targeted, had improved. Although the PC-based training program only provided top-down views of the scenarios, the results on the driving simulator show that the training with top-down views can generalize to the dynamic, perspective views projected on the simulator (and present in the real world).

Several other training programs, which targeted at different driving skills such as attention maintenance (Pradhan et al., 2011), speed management (Muttart, 2011), or different age groups of drivers (Romoser et al., 2009), or other safety-related driving behavior (Lenne et al., 2011), have been proved to be effective as well. The studies mentioned above all used 3M training method, and evaluate the effect of training on the driving simulator, which have provided valuable insights and guidance for the design and development of this training program. Thus it is decided that the training program developed in this study will use the same 3M training method that proved to be effective, and in order to evaluate the effectiveness of the training program, an evaluation drive that contains both near transfer scenarios and far transfer scenarios will be given to the participants.

CHAPTER 3

METHOD

In this study, a simulator-based training program, LAG (Less Aggressive Goals), was designed and evaluated. The LAG training program targeted younger drivers' unsafe aggressive driving, specifically addressing unnecessary quick accelerations and unsafe quick decelerations. Participants were asked to drive through a virtual world before and after receiving either LAG training or placebo training. Participants' eye movements and simulator data, such as speed, acceleration rate, throttle position, brake position, and time headway were recorded throughout the drives. The differences in behaviors before and after the training, as well as the differences across the two groups were evaluated.

3.1 Participants

A total of thirty-six younger drivers, aged from 18-19 years old (average: 18.39, SD: 0.49), with less than 2 years driving experience (average: 1.55, SD: 0.50), were recruited for the study. Participants were randomly assigned to either the LAG training group, or the placebo training group. Each group had eighteen participants.

3.2 Apparatus and stimuli

3.2.1 Driving Simulators

The personal computer based, interactive driving simulator in the Arbella Insurance Human Performance Laboratory (HPL) at the University of Massachusetts Amherst was used for the training session in this study. The simulator STISIM is

manufactured by Systems Technology Inc. (STI). The simulator allows the driver to control all aspects of driving including the vehicle's speed and steering. The virtual driving scene is displayed on three screens in front of the driver which gives the driver a 135 degree field of view horizontally and 30 degrees vertically. The images are displayed at a resolution of 1280 x 1024 pixels in each screen with a refresh rate of 60 Hz. A surround sound audio system is embedded in the simulator. The audio system provides appropriate vehicle noise and all the scripted oral turn instructions.

Another driving simulator, which is the fix-based full-size driving simulator in the Arbella Insurance Human Performance Laboratory (HPL) at the University of Massachusetts Amherst, was used for the evaluation drives in this study. This simulator, manufactured by Realtime Technologies Inc., consists of a full size 1995 Saturn sedan. The virtual driving scene is displayed on three screens which subtend 150 degrees of visual angle horizontally and 30 degrees vertically. The images are displayed at a resolution of 1024 x 768 pixels in each screen with a refresh rate of 60 Hz. A surround sound audio system is also embedded in the RTI simulator.

3.2.2 Eye Tracker

The Applied Science Laboratories (ASL) Mobile Eye, a light weight tetherless Eye Tracking System (ETS), was used to monitor participants' eye movements. The system uses pupil-corneal reflections as the measurement principle. The sampling and output rates are 30 Hz and the system allows the driver's head a full range of motion. The system's accuracy is 0.5 degrees of visual angle.

3.3 Experimental procedure

When participants first came to the lab, they received instructions describing the study. After all the paperwork was completed, participants were fitted with the head-mounted eye-tracker, which was calibrated for each participant. Each participant then completed a practice drive. The practice drive was included to familiarize participants with the controls of the RTI simulator. The pre-training evaluation drive was completed next. Participants' eye movements and simulator data, such as velocity, acceleration rate, throttle position, brake position, and time headway were recorded throughout the drive. The pre-training evaluation drive consisted of eight different scenarios (described below). The drive took approximately 15 minutes. After finishing the pre-training evaluation drive on the RTI simulator, participants in the training group received the LAG training program on the STI simulator. Participants were given another practice drive on the STI simulator to get them familiar with this simulator and then began their training program with the instructor's guidance. The LAG training program took approximately 30-45 minutes. Participants in the control group did not receive the practice drive for the STI simulator and, instead, began their placebo training immediately after they have finished the pre-training evaluation drive. The placebo training would take approximately the same time as the LAG training program. Both groups were asked to undertake a post-training evaluation drive on the RTI driving simulator once they finished the training programs.

The placebo training provided to the participants was a pc-based interactive program developed by Dunlap & Associates, Inc. The program showed participants the

real-world traffic scene videos and participants were asked to click on where they would look if they were driving. Participants did not receive any feedback from the program.

3.4 Training Scenarios: STI

As mentioned earlier, the participants were randomly assigned to either the LAG training group, or the placebo training group. Six scenarios were developed for the LAG training program. Three of the six scenarios were designed to teach teen drivers the dangers of unsafe quick acceleration behaviors which occur in scenarios such as intersections when drivers fail to glance for potential threats, while the others were designed to teach teen drivers the dangers of unnecessary quick decelerations which occur in scenarios such as ones where the driver fails to keep a proper following distance.

The LAG training program included the three elements that have been shown across a large number of driver training programs, for both younger (e.g., Pollatsek et al., 2006) and older (e.g., Romoser & Fisher, 2009) adults, to be effective: mistakes, mitigation and mastery. First consider the scenarios developed to teach participants the dangers of unsafe quick acceleration. (1) Mistakes. During the LAG training session, participants were given the three quick acceleration scenarios one at a time. Hazards in the scenarios were materialized. There was some possibility that drivers would be in a crash or near crash. (2) Mitigation. After each scenario was completed, participants received feedback specific to the scenario which indicates what it was to which they should pay attention, how to anticipate hazards, and how to mitigate those hazards. (3) Mastery. Once participants had been given feedback, they were given another chance to drive the same scenario with the materialized hazards. This gave them the ability to

master the elements of the potentially hazardous scenario and to correct their previous mistakes or to strengthen their knowledge of what they had learned.

Next consider the scenarios designed to teach the participants the dangers of unnecessary quick decelerations. (1) Mistakes. Instead of receiving feedback on the scenarios one at a time, participants drove 3 scenarios in which they were asked to maintain a specific gap between their vehicle and a lead vehicle, the gap being on the order of 3 seconds, 2 seconds, or 1 second. The primary goal of these three scenarios was to give participants the actual experience of not being able to stop in time when the lead vehicle suddenly decelerates if the time headway was too small, something that can be experienced in a driving simulator safely enough, but not on the open road. (2) Mitigation. The feedback explaining the potential hazards and what to do was given after these three scenarios had been provided to the driver. (3) Mastery. After the feedback, participants were asked to follow at a distance with which they were comfortable with while still attempting to maintain as small a time headway as possible.

3.4.1 Quick Acceleration Scenarios

As noted above, three scenarios in the training program were designed for training drivers to avoid quick accelerations. The scenarios were confined to intersections and crosswalks, where most of the potentially dangerous, quick accelerations take place (Predhan et al., 2005; Romoser et al., 2012). In Training Scenario 1, shown in Figure 1, the driver was approaching a signalized 4-way intersection with a green light and preparing to turn left. There were four travel lanes, two in each direction. A line of five cars in the opposing lane traveled straight through the intersection after the driver entered

the intersection but before the driver turned. A gap then appeared in the line of traffic which, if the driver quickly accelerated, was just large enough to enter. However, at the end of the gap a truck coming from the opposing direction in the fast lane was going straight and gave no sign of turning. A coupe from the opposing direction in the adjacent slow lane was going straight as well. The driver could barely see the coupe from his or her point of view because vision of the coupe was blocked by the oncoming truck. If the driver aggressively turned in the gap before the truck, there was a high possibility that a crash would happen. What a driver should do here is to reduce the speed while approaching the intersection and patiently wait until his/her front view is clear, and then proceed with the turn.
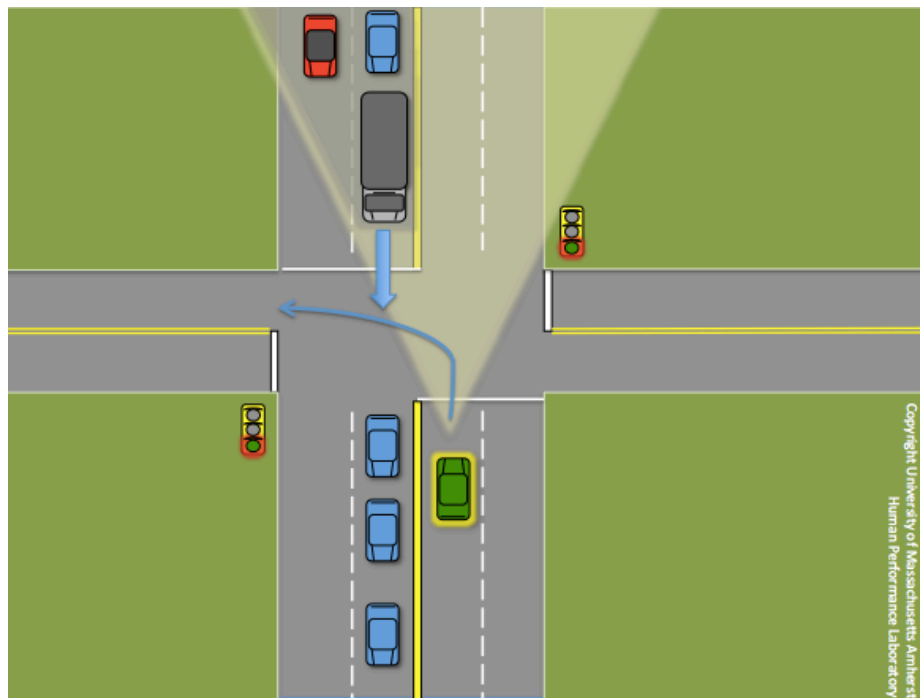
Figure 1. Training Scenario 1 - Oncoming Truck Driver Left Turn
(Participant's vehicle is green and outlined in yellow. His or her unobscured view is the cone highlighted in yellow. The threat is the red vehicle in the upper left.)

In Training Scenario 2, the driver was approaching a T-intersection and preparing to turn right (Figure 2). The driver's view to the right was blocked by a row of hedges. A line of vehicles appeared in the driver's field of view on the left and gave no sign of turning when the driver was about to cross the intersection. The gap between the first 4 vehicles varied, but all were risky. The gap between the 4th and 5th vehicle was much larger. No traffic appeared from the right. If the driver only scans to the left side after stopping and then turns between the 4th and 5th vehicle, he or she could easily collide with a pedestrian or a bicyclist crossing the crosswalk from the right on the sidewalk. The appropriate behavior here for the driver is to first stop at the stop sign, frequently monitor the area to the left and to the right until both ways are clear, and then proceed through the turn.

Figure 2. Training Scenario 2 – Bicyclist Crossing From Right Driver Right Turn
(The threat is the bicyclist highlighted in red coming from the right of the intersection.)

In Training Scenario 3, the driver was coming to a crosswalk and must stop for crossing crossing pedestrians

Figure 3). A bus stopped at the bus stop in front of the crosswalk, which blocks the driver's view to the far right. If the driver aggressively proceeds over the crosswalk when a gap first appears, it is highly possible that he or she might hit an upcoming bicycle or pedestrians at a relatively high speed that were previously obscured by the bus. The appropriate approach here after the driver has stopped would be for the driver to inch forward towards the crosswalk slowly until his or her views of both the left and right are clear before accelerating.
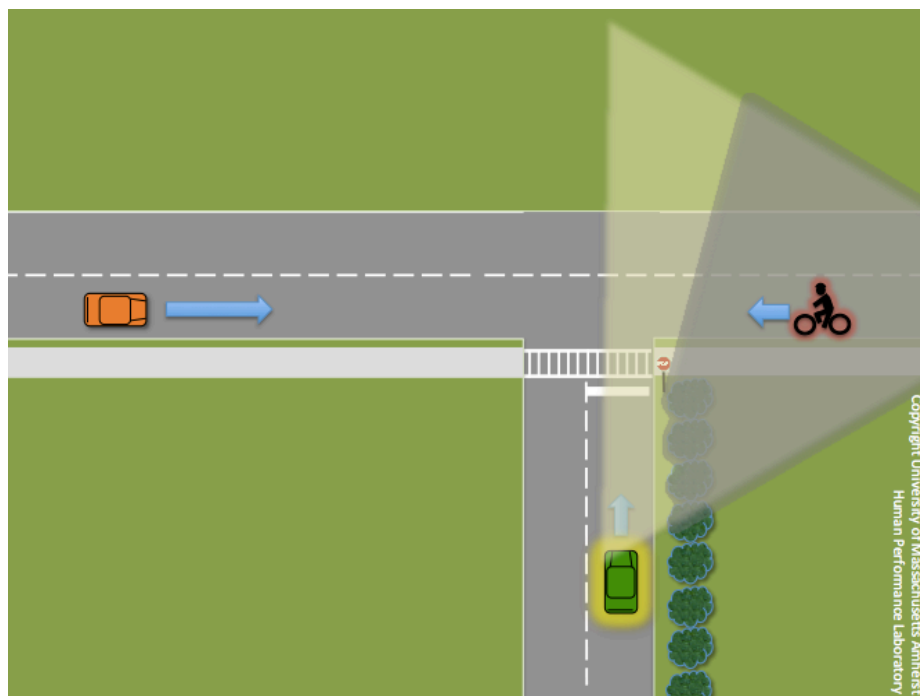
Figure 3. Training Scenario 3 – Bicyclist Crossing Driver Going Straight
(The threat is the bicyclist highlighted in red coming from the right of the crosswalk.)

3.4.2 Quick Deceleration, Tailgating Scenario

Quick decelerations usually happen when drivers fail to recognize that the following distance between their vehicle and the vehicle in front is too small to be able to stop in time when the vehicle ahead makes an emergency stop. As noted above the quick decelerations are defined here as unnecessary if the driver could have avoided the quick deceleration by following at a larger distance. For training purposes, three scenarios were designed. The lead vehicle travelled at a constant speed in front of the participant and then at some apparently random time stopped suddenly. The participant's primary task was to follow the lead vehicle at, respectively, a 3-second gap, a 2-second gap, and a 1-second gap during the three scenarios. Poles were placed on the right side of the road for the participants to estimate their following distance. The distance between two poles was

the required following distance. The gap scenarios were presented in order of their size to avoid the problem that a first crash might pose. By giving the driver the 3 second gap scenario first, the driver is alerted – whether a crash occurs or not – that the lead vehicle could stop suddenly. Thus, given that a crash cannot be avoided with the 2-second and 1-second gap scenarios, the driver will learn that even when hypervigilant he or she cannot avoid a crash when following too closely. Participants were not told in advance when the lead vehicle would make an emergency stop.

3.5 Evaluation Scenarios: RTI

Participants completed a pre-training and post-training evaluation drive before and after the training program. Hazards in the scenarios in both the pre-training evaluation drive and the post-training evaluation drive were not materialized. However, the hazard in the quick deceleration scenario, which was the lead vehicle when it suddenly stopped, was materialized in the post-training evaluation drive. This makes it possible to compare the effects of LAG training and placebo training. The sequences of the scenarios in the pre- and post-training evaluation drive varied across participants within the LAG and placebo groups.

Scenarios in the evaluation drives were divided into two categories, near transfer scenarios and far transfer scenarios. Near transfer scenarios were defined as scenarios that were similar or identical to what LAG trained participants were exposed to in the training program. Far transfer scenarios were defined as scenarios that were markedly different from those in the LAG training program, but required the same general skills

that the training program targeted. There were four near transfer and four far transfer scenarios developed for the evaluation drive.

3.5.1 Near Transfer Scenarios

In this study, the four near transfer scenarios were designed to be as similar to the scenarios given in the LAG training program as possible, except that the all the threats in the training scenarios were not materialized in the near transfer scenarios. Three of them were the quick acceleration scenarios, which were described in details previously. The fourth scenario was the quick deceleration scenario (marked as Near Transfer Scenario 4), in which a lead vehicle would make an emergency stop without drivers expecting it to stop. In both the pre-training and post-training evaluation drives participants could maintain whatever distance they felt was comfortable between their vehicle and the lead vehicle. Specifically, the software was not used to control either the distance or the time between the lead vehicle and the driver's vehicle.

3.5.2 Far Transfer Scenarios

Four far transfer scenarios were designed for the evaluation drive. In Far Transfer Scenario A (Figure 4), the driver would come to a stop sign controlled intersection and, the cross traffic had the right of way. This is a far transfer from Training Scenario 2. In Training Scenario 2, the participants were trained to look to the right when turning into the right; in Far Transfer Scenario A, the driver was expected to look to both left and right while going straight at the intersection. What is interesting here is to see if the driver looked to the far left and far right, if the driver fully stopped at the intersection and at what speed, acceleration and throttle position did the driver crossed the intersection.
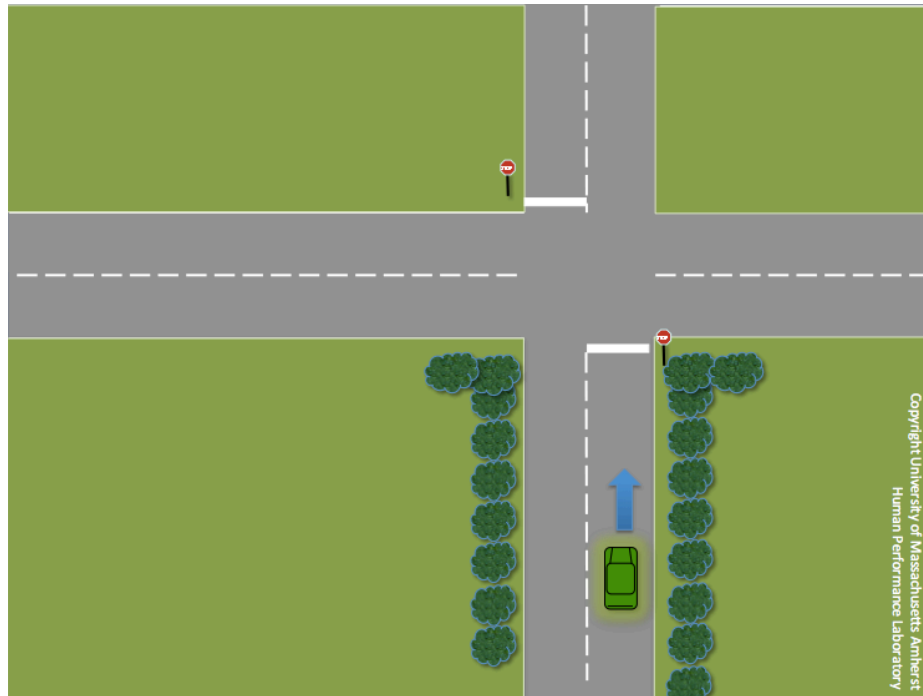
Figure 4. Far Transfer Scenario A – Stop Sign Intersection Driver Continue Straight

In Far Transfer Scenario B, the driver approached a stop sign-controlled intersection (Figure 5). The cross traffic was coming from the left with gaps in the order of 2 seconds, 3 seconds, 4 seconds, 5 seconds, 6 seconds, 2 seconds, 3 seconds, 4seconds, 5seconds, 6 seconds. The cross traffic had the right of the way. The views to both the right and the left were obscured. This is a far transfer from Training Scenario 1. In the Training Scenario 1, the participants were taught how to differentiate a safe gap while turning left; in Far Transfer Scenario B, the participants needed to choose a safe gap as well while continuing straight at the intersection. The cautious driver should look to the left and right to make sure the gap he/she is taking is safe enough before accelerating. What I looked at here were which gap the driver took, the eye behaviors before the driver's action, the velocity, the acceleration and the throttle position.
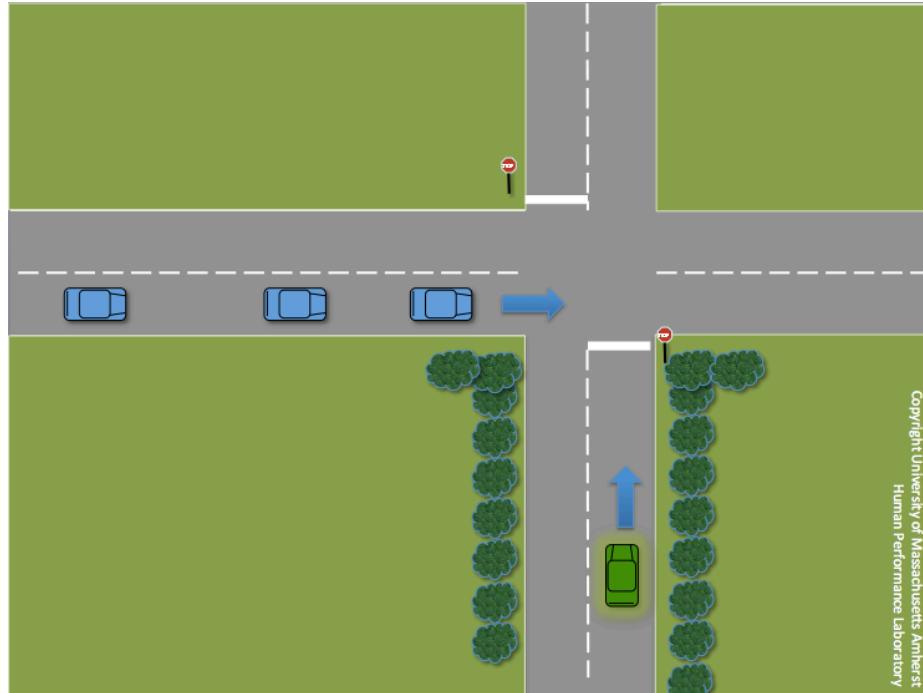
Figure 5. Far Transfer Scenario B - Cross Traffic Driver Gap Acceptance

In Far Transfer Scenario C (Figure 6), the driver approached a four-way signalized intersection. The signal turned from green to yellow 2-3 seconds before the driver reached the intersection, depending on the driver's speed. The driver would need to increase the speed in order to make it through the intersection before the signal turns from yellow to red. Far Transfer Scenario 3 can be considered as a far transfer from the quick deceleration scenario if participants stopped at the intersection, or a general overview of aggressive driving maneuvers.
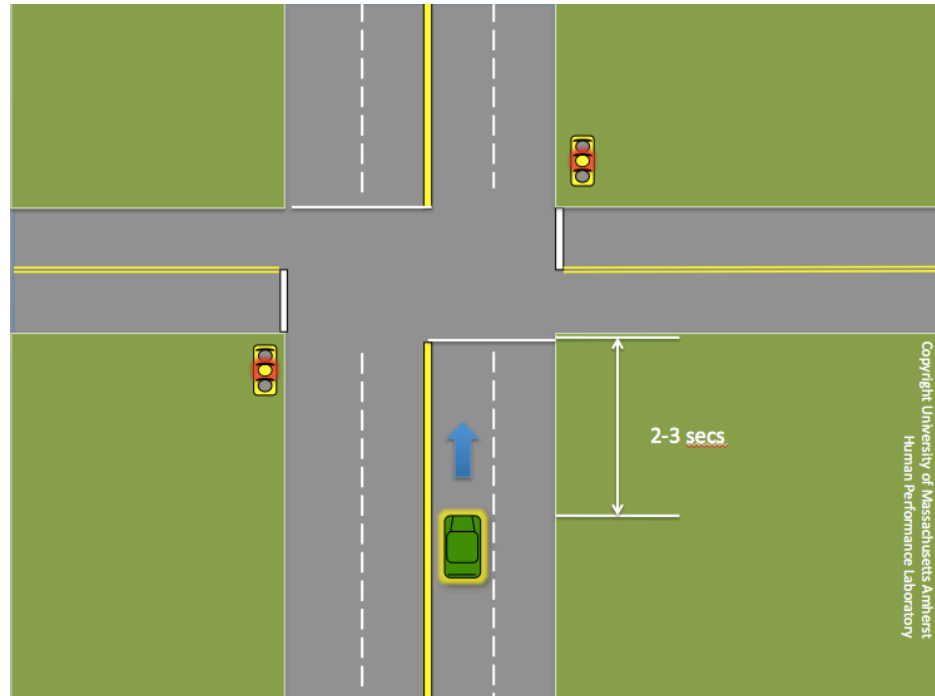
Figure 6. Far Transfer Scenario C - Fresh Yellow Intersection

In Far Transfer Scenario D (Figure 7), the driver, again, approached a four-way signalized intersection with a red light and intends to go straight. There was a truck coming from the same direction stopped in a dedicated left turn lane and intended to turn left (left turn signal is on). The truck stopped beyond the stop bar and therefore blocked the driver's view to the left. The driver would wait at the intersection for 5 or 6 seconds for the light to turn green. A pedestrian was materialized to stop at the intersection. This is a far transfer from Training Scenario 3. In the Training Scenario 3, the participants' view to the right was block by a bus and the hazard – a bicyclist – was coming from the right; while in Far Transfer Scenario D, both the obscured vision and the potential hazard was from the left. I was interested in the driver's eye behaviors, specifically if the driver looked to the left before accelerating when the light turned green, since the truck was not immediately turning and there was no oncoming traffic coming toward the intersection, which indicated that a pedestrian might be crossing the intersection. Drivers' eye

behaviors, vehicle velocity, acceleration and throttle position of the driver crossing the intersection were analyzed.
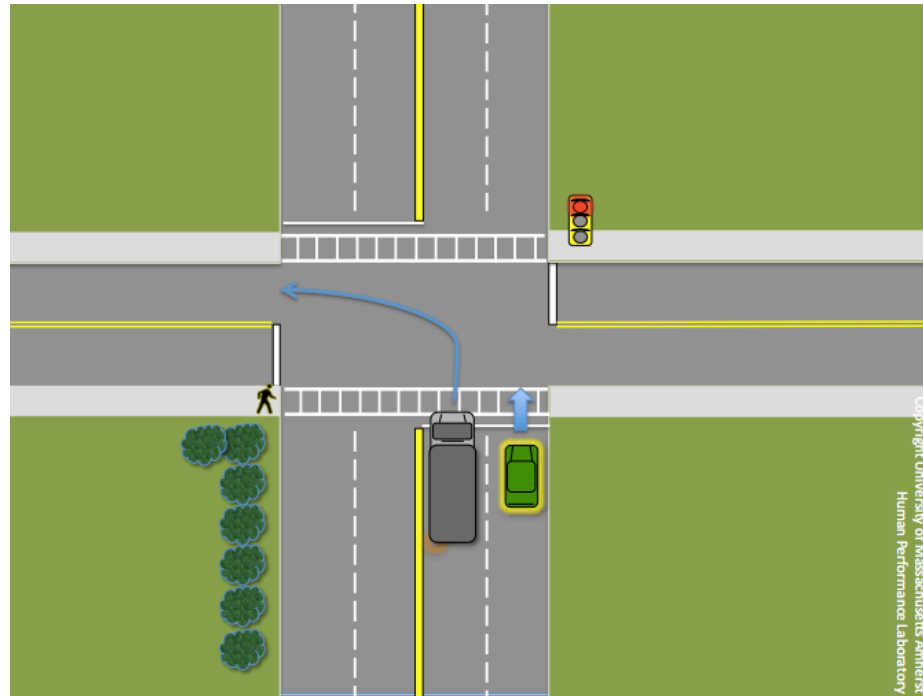
Figure 7. Far Transfer Scenario D - Truck Left Turn Driver Continue Straight

3.6 Design

As alluded to above, the four near transfer scenarios were labeled arbitrarily 1, 2, 3, and 4 (the logic for each of the three quick acceleration scenarios is displayed in Figure 1 - Figure 3), and the four far transfer scenarios were labeled arbitrarily A, B, C, and D (the logic for these four scenarios is displayed in Figure 4 - Figure 7). The scenarios were randomly sequenced and stitched together as two drives, labeled I, I', II and II'. The prime indicates that the lead vehicle stopped suddenly in the quick deceleration scenario. The absence of a prime indicates that the lead vehicle did not stop suddenly. The orders of the drive were counterbalanced in the pre-training and post-training drives in both groups. Participants navigated through a drive that contained all the scenarios with

unmaterialized hazards randomly ordered before the training program, and another drive with the same scenarios all included but materialized hazard in the emergency scenario in another random order after they finished the training program. Thus, the orders were I- II' or II - I'.

3.7 Hypotheses, Independent Variables, and Dependent Variables

At a global level, it is hypothesized that the drivers who received the LAG training program scenarios in the post-training evaluation drive would drive more defensively than the drivers who received the placebo training. More specifically, in the quick acceleration scenarios it is hypothesized that the LAG trained drivers will have more glances to the target zone where potential hazards could occur and will have fewer quick accelerations. And in the quick deceleration scenarios, it is hypothesized that the LAG trained drivers will follow at larger time headways and have fewer quick decelerations. The set of hypotheses specific to each scenario is listed in Table 2 below.

Training condition and pre/post-training status were considered as the independent variables in the study. The training condition was considered as a between-subject variable, the pre/post-training status was considered as a within subject variable. Simulator data, specifically vehicle velocity, acceleration rate, headway, throttle position, brake position and subjects' eye behavior data were the dependent variables in the study. The dependent variables of each scenario are also listed in below. The manner in which the dependent variables are measured in each scenario varies and is discussed in the Results section.

Scenario	Dependent Variables and Hypotheses
Near Transfer Scenario 1	*Hypothesis:* The number of the participants who took the gap in the trained group was expected to be less than the number of the participants in the placebo group. The participants in the trained group were expected to travel and accelerate more slowly into the turn after stopping before turning.
	Dependent Variables: Gap Taken Rate (1 – took the gap; 0 – did not take the gap); vehicle velocity; vehicle throttle position; vehicle acceleration.
Near Transfer Scenario 2	*Hypothesis:* The participants in the trained group would have more glances towards the target zone (the area to the right in front of the bushes). The participants in the trained group would accelerate less quickly than the participants in the placebo group.
	Dependent Variables: Percentage of glances to the target zone (1 – looked; 0 – did not look); vehicle velocity; vehicle throttle position; vehicle acceleration.
Near Transfer Scenario 3	*Hypothesis:* The participants in the trained group were expected to have more glances toward the target zone (the area in front of the bus). The percentage of the participants who slowed down yielding to potential pedestrians in the trained group was expected to be higher the percentage of the placebo group. The participants in the trained group were expected to accelerate less quickly.
	Dependent Variables: Percentage of glances to the target zone (1 – looked; 0 – did not look); vehicle velocity; vehicle throttle position; vehicle acceleration.
Near Transfer Scenario 4 (Quick Deceleration Scenario)	*Hypothesis:* The participants in the trained group would have fewer crashes than the participants in the placebo group. The participants in the trained group would brake less hard and maintain a larger time headway.

	Dependent Variables: Whether the participants crashed (0 – did not crash; 1 – crashed); crash data; vehicle velocity; vehicle brake position; vehicle time headway.
Far Transfer Scenario A	*Hypothesis:* The participants in the trained group would have more glances to both two target zones (far left and far right) than the participants in the placebo group. The participants in the trained group would accelerate less quickly.
	Dependent Variables: Percentage of glances to the target zones (1 – looked; 0 – did not look); vehicle throttle position; vehicle acceleration.
Far Transfer Scenario B	*Hypothesis:* The participants in the trained group would have more glances to the target zone (far right) than the participants in the placebo group. The participants in the trained group would accelerate less quickly.
	Dependent Variables: Percentage of glances to the target zone (1 – looked; 0 – did not look); vehicle throttle position; vehicle acceleration.
Far Transfer Scenario C	*Hypothesis:* The participants in the trained group would accelerate less quickly (if they crossed the intersection), or brake less hard (if they did not cross the intersection) than the participants in the placebo group.
	Dependent Variables: Percentage of the participants that crossed the intersection; vehicle throttle position (if applicable); vehicle brake position (if applicable).
Far Transfer Scenario D	*Hypothesis:* The participants in the trained group would have more glances to the target zone (far left at the crosswalk) than the participants in the placebo group. The participants in the trained group would accelerate less quickly.
	Dependent Variables: Percentage of glances to the target zone (1 – looked; 0 – did not look); vehicle throttle position; vehicle

	acceleration.

Table 2. List of hypotheses and dependent variables

CHAPTER 4

RESULTS

4.1 Quick deceleration Scenario

As the quick deceleration scenario in the pre-training drive was different from the one in the post-training drive, all analyses were conducted separately for the pre-training and post-training drive.

In the pre-training drive, the hazard in the quick deceleration scenario was not materialized. The drivers only needed to follow the lead vehicle at their own preferred distance. The average time headway and the average speed throughout the scenario were analyzed. An independent-samples t-test with the training condition as the between-subjects factor revealed no significant difference in the average time headway of the LAG and placebo groups (Figure 8), or the average velocity of the LAG and placebo groups (Figure 9).

	Pre
Placebo	1.65
Train	1.72

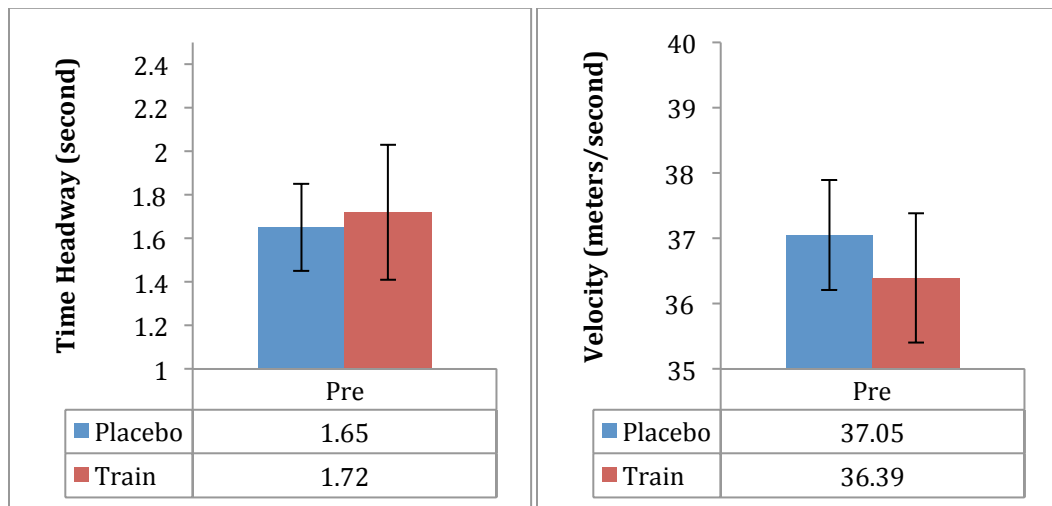|	Pre
Placebo	37.05
Train	36.39

Figure 8. Pre-training – average time headway   Figure 9. Pre-training – average velocity

In the post-training evaluation drive, the hazard was materialized. The lead vehicle would come to a sudden stop without the driver being able to predict if or when the sudden stop would occur. The crash data as well as the vehicle data, specifically vehicle speed, brake position, headway, were analyzed. Hypothetically, the trained drivers would have fewer crashes than the placebo drivers. The trained drivers would brake less hard and maintain larger time headway than the placebo drivers.

A logistic regression in the framework of Generalized Linear Model (GLM) was used to compare the crash rates of the LAG trained group and the placebo group. Participants were included as random effects. The dependent variable was defined as whether a participant crashed into the lead vehicle (0 - didn't crash into the lead vehicle; 1 – otherwise). No significant difference was found. The results are displayed in Figure 10 below.

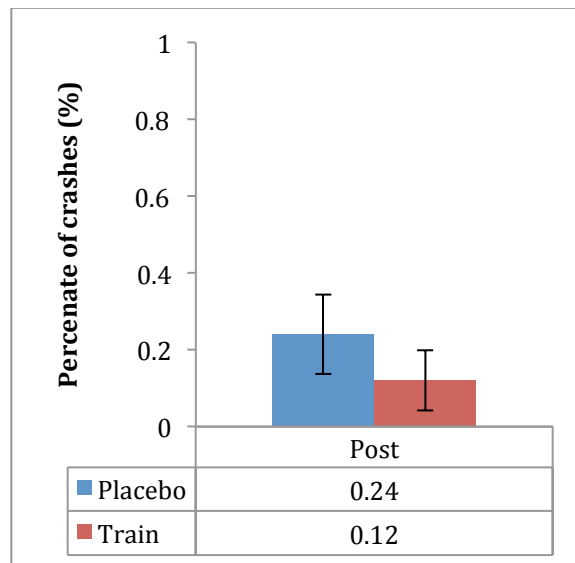|	Post
Placebo	0.24
Train	0.12

Figure 10. Post-training – percentage of crashes

Define the time when participants reached their minimum speed in this scenario as the *reference point*. The "find minimum value" function in Excel was used to identify the minimum. No smoothing was done over small intervals of time since the participants had to slow for the lead vehicle and the velocity data of each participant is in a clear "V" shape. The changes of the vehicle related dependent variables 5 seconds prior to the reference point were analyzed. These vehicle-related dependent variables are velocity, brake position, and time headway. A Linear Mixed Model with a random intercept was conducted to evaluate the dependent variables. Two fixed effects were included in the model: (1) Between subjects factor – Training Condition, (2) Within subject factor – Time prior to Reference Point. Participants were included as random effects. The values being analyzed are the average values over each one-second interval. A pairwise comparison post hoc analysis using a sequential Bonferroni correction was then conducted to explore the differences between the LAG trained group and the placebo group at each second.

Figure 11 shows the average velocity in each one second of the five seconds preceding the reference point (i.e., the point when the participants reached the minimum speed in this scenario). The labels "V5s, V4s,…, V1s" on the X-axis indicate the average velocity within the 5th one-second, the 4th one-second,…, the 1st one-second before the reference point. There were significant differences in both of the main effects: the Training Condition ($F[1] = 14.263, p < .001$), and the Time prior to Reference Point ($F[4] = 55.023, p < .001$). The post-hoc analysis revealed a significant difference in the 4th second (t[20] = 2.109, p = .048), a marginal significance in the 3rd second (t[28] = 2.010, p = .054), and a trend in both the 2nd second (t[31] = 1.627, p = .114), and the 5th

second (t[13] = 1.617, p = .130). In general, the participants in the placebo group were travelling faster than the participants in the trained group. The trend is consistent with the hypothesis. Specifically, the participants in the trained group were travelling significantly more slowly than the participants in the trained group starting from the 4 seconds before they reached the minimum speed.
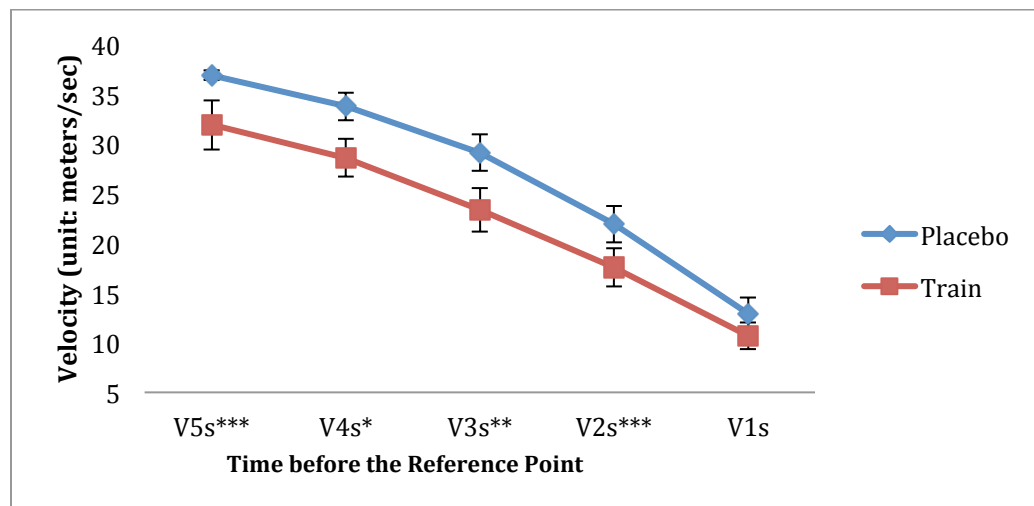

Figure 11. Changes in velocity over 5 Seconds to the reference point.
(Standard error bars added. * - significance, ** - marginal significance, *** - trend.)

Figure 12 displays the trend of brake position. A significant difference was found in the main effect of the Time prior to Reference Point ($F[4] = 8.737, p < .001$). The post hoc analysis revealed significant trends in the 4th second ($t[20] = -1.625, p = .120$) before slowing to a minimum, and in the 1st second ($t[32] = 1.369, p = .180$) before slowing to a minimum, indicating that the participants in the trained group (Mean = 57.27, unit: degrees, SE = 10.55) had depressed the brake further than the placebo group (35.35, 7.59) 4 seconds prior to the minimum, but had depressed the brake less 1 second prior to the minimum (Trained: 51.44, 14.47; Placebo: 77.64, 12.50). In addition, the general trend of the brake positions of the placebo group showed a linear increase

from the 5th second to the 2nd second, and maintained at the maximum value at the 1st second. By comparison, the brake position of the trained group started at about the same value as the brake position of the placebo group in the 5th second, reached the maximum value at the 4th second, and decreased after that. Such a trend indicated that when both the participants in the trained group and in the placebo group detected the lead vehicle braking at about the same time, the participants in the trained group in general braked earlier and overall less hard than the participants in the placebo group.

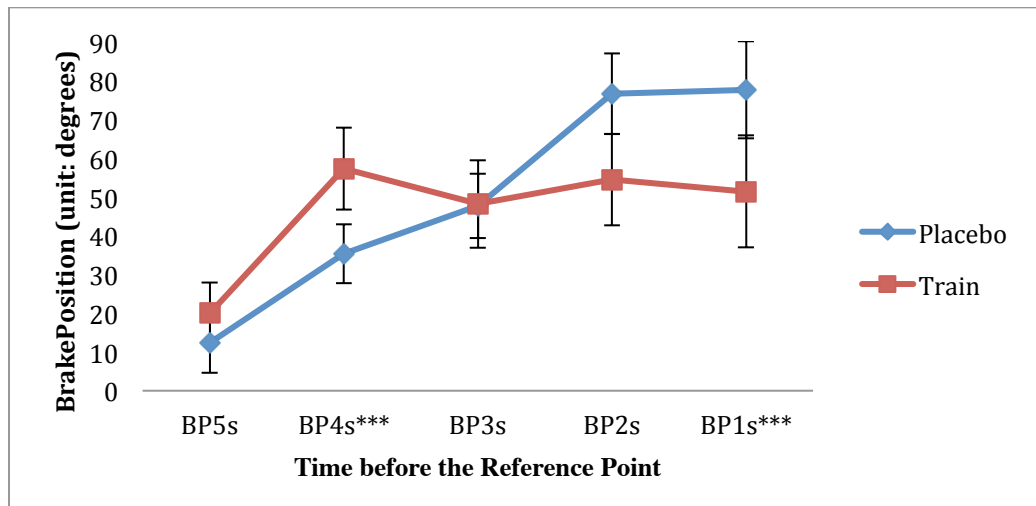Figure 12. Changes in brake position over 5 seconds to the reference point

Figure 13 displays the changes of the headway in time over the 5 seconds prior to the reference point. Although no significant differences were found in the main effects, nor at any of the five measurement points, the trend indicated that the participants in the trained group tended to have a larger time headway than the participants in the placebo group.
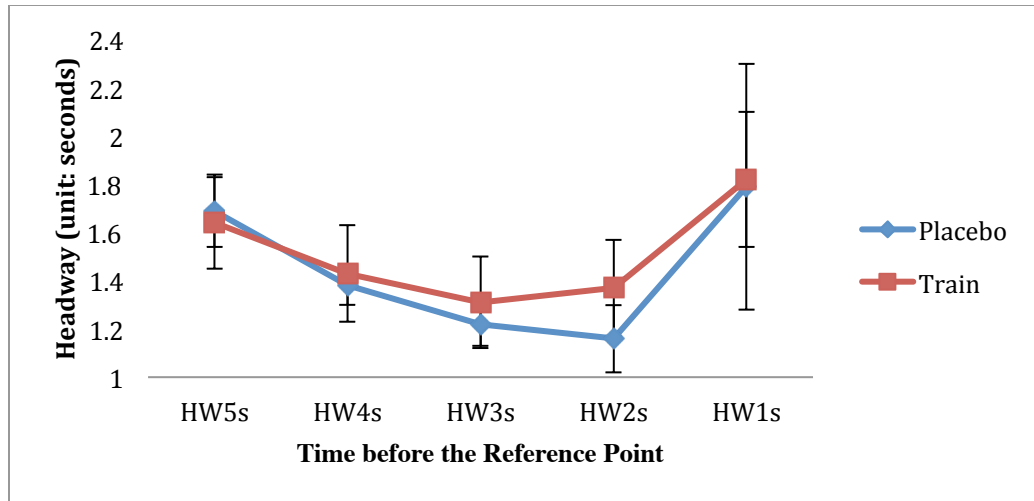
Figure 13. Changes in headway in time over 5 seconds to the reference point

4.2 Quick acceleration scenarios

All the quick acceleration scenarios were the same in the pre-training and post-training drives. In order to further explore the participants' driving behaviors, the changes in vehicle related dependent variables over 3 seconds from the reference point were extracted and discussed. The values of the vehicle related dependent variables that were being analyzed are the average values within one-second interval. If not specified otherwise, all the vehicle related dependent variables such as velocity, throttle position, and acceleration listed below were analyzed using a Linear Mixed Model with a random intercept in SPSS. Participants were included as random effects. There were three fixed effects: the Training Condition (placebo vs. train) was included as the between-subjects factor, the Pre/Post Status and the Time from Reference Point (the 1st one-second from the reference point, the 2nd one-second from the reference point, and the 3rd one-second from the reference point) were included as the within-subjects factor. The reference point of each scenario is specified below. Unless specified otherwise, all the eye measurement

data below were analyzed using a logistic regression in the framework of Generalized Estimated Equations (GEE). The fixed effects were: 1) a within-subjects factor (Pre/Post Status), and 2) a between-subjects factor (Training Condition). Participants were included as a random effect. The launch zone and the target zone of each eye measurement variable are described in detail below.

4.2.1 Near Transfer Scenario 1

In the Near Transfer Scenario 1 (Figure 1), the participants came to a signalized 4-way intersection with the green light and were waiting to turn left. A gap large enough for a very quick turn, but generally not considered safe, appeared in the line of traffic in the opposing direction, as the truck after this gap blocked the participants' view of the traffic that might be in adjacent lane traveling in the same direction. Hypothetically, the number of the participants who took the gap in the trained group was expected to be less than the number of the participants in the placebo group. The participants in the trained group were expected to travel and accelerate more slowly into the turn after stopping before turning.

The dependent variables of this scenario were whether the participants took the gap, the vehicle velocity at the reference point (see following), the vehicle velocity three seconds after the reference point, the throttle position, and the acceleration. The *reference point* was defined as the time after slowing and entering the intersection when the participants first started increasing their velocity. Specifically, all of the participants had to slow down here and then accelerate. The graph of velocity across time had the she of a

"V". The reference point here is the first non-zero value in the throttle position after the minimum value of velocity.

For the gap analysis, the participant was scored as either 1 or 0: 1 if the participant took the gap, 0 if the participant didn't take the gap. There were significant main effects of Pre/Post Status ($\chi^2_{1_{wald}} = 8.003, p = .005$) and Training Condition ($\chi^2_{1_{wald}} = 13.298, p < .001$). The interaction was not significant. The percentage of the participants that took the gap is shown in Figure 14. Although there was no significant interaction between the two conditions, a pairwise comparison post hoc analysis using a sequential Bonferroni correction was performed to further explore the interaction. It was found that in the pre-training drive, the percentage of the participants that took the gap in the trained group was marginal significantly smaller than the percentage of the placebo group ($\chi^2_1 = 3.238, p = .072$); in the post-training drive, the percentage of the trained group that took the gap was significantly smaller than the percentage of the placebo group ($\chi^2_1 = 18.836, p < .001$). The trend clearly shows a decrease in the percentage of the participants who took the gap in the trained group. Due to the small proportions, the eye behaviors of the participants who took the gap were omitted.
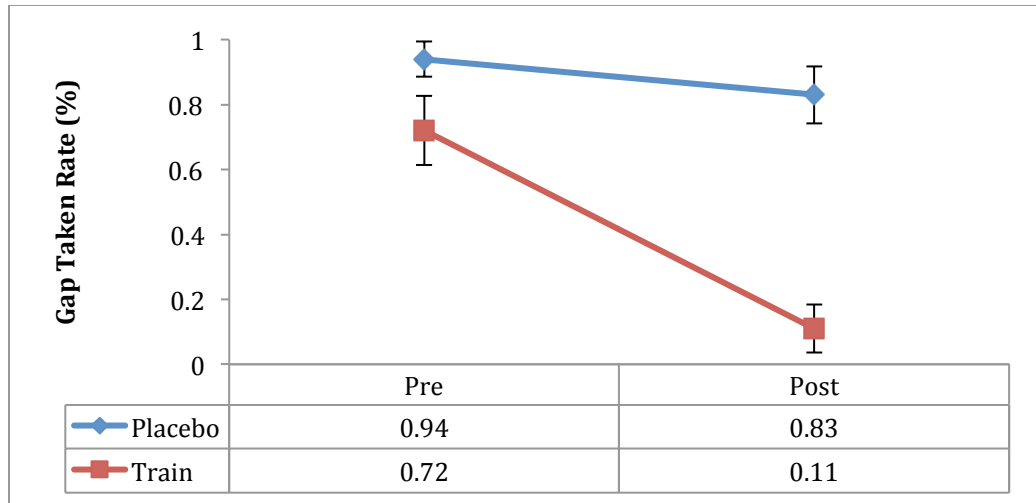
Figure 14. Percentage of the participants that took the gap

The data on initial velocity is shown in Figure 15. The initial velocity is defined as the velocity when participants first depressed the gas pedal after they reached the minimum speed. There were significant main effects of the Pre/Post Status ($F[1,33] = 10.587, p = .003$), and the Training Condition ($F[1,33] = 5.304, p = .028$). A pairwise comparison post hoc analysis using a sequential Bonferroni correction revealed a marginally significant difference in the interaction ($F[1,33] = 3.703, p = .063$).
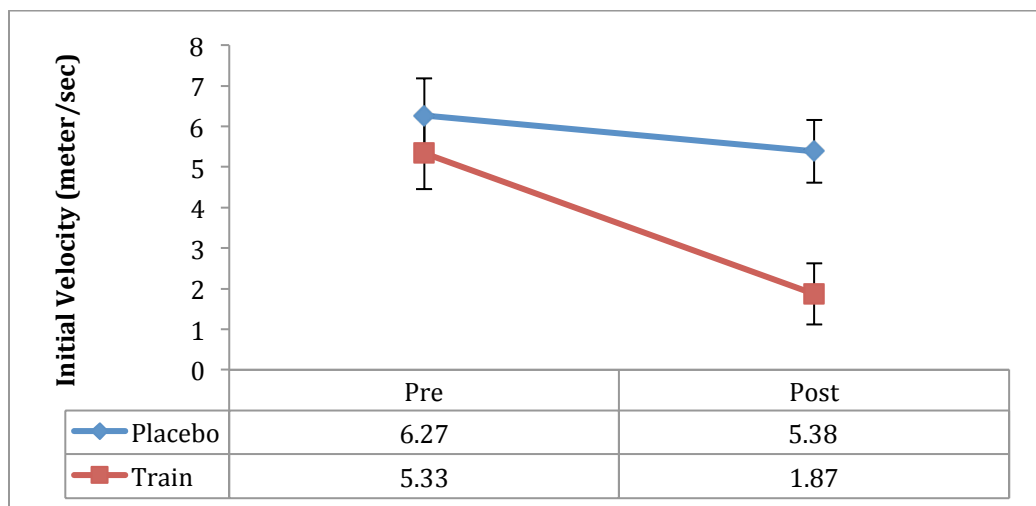

Figure 15. The initial velocity during the acceleration process.
(Initial velocity is measured after the onset of the reference point.)

Figure 16 shows the changes in velocity (unit: meters/second) over 3 seconds from the reference point. There were significant differences in all the main effects: the Training Condition ($F[1] = 27.699, p < .001$), the Pre/Post Status ($F[1] = 18.232, p < .001$), and the Time from Reference Point ($F[2] = 110.187, p < .001$). A backward elimination procedure (beginning with a model including all variables and then taking out non-significant effects) was applied afterwards to explore the effect of the different independent variables. No significant differences in the interactions were found.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training velocity and post-training velocity between the trained-group and the placebo group at each second. A marginally significant difference was found in the 1st second ($t[33] = 1.826, p = .077$).
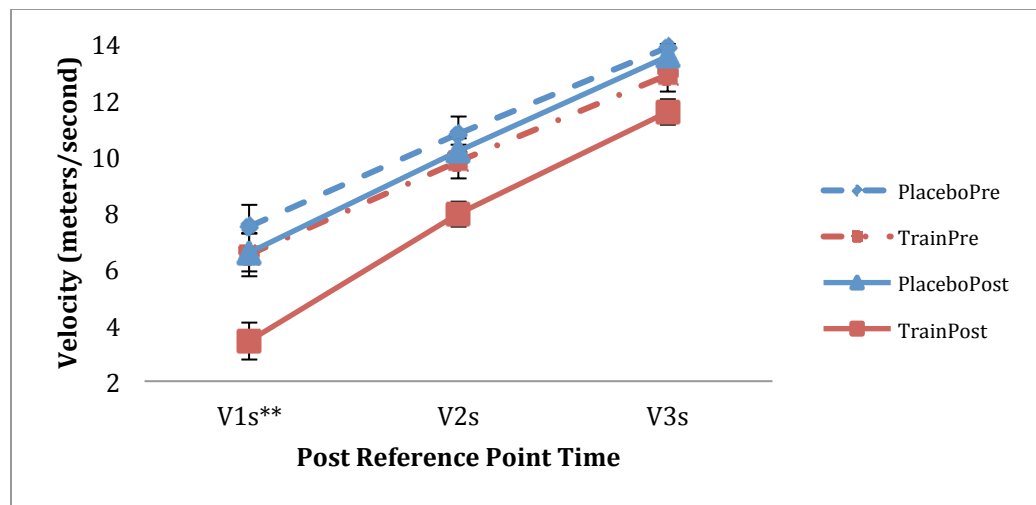

Figure 16. Changes in velocity over 3 seconds from the reference point
(** - Marginal significance in the difference score between pre and post-training drive)

Figure 17 displays the changes in acceleration (unit: $meters/second^2$) over 3 seconds from the reference point. There were significant differences in all three main

effects: the Training Condition ($F[1] = 4.592, p = .034$), the Pre/Post Status ($F[1] = 11.515, p = .001$), and the Time from Reference Point ($F[2] = 6.280, p = .002$). A backward elimination procedure revealed no significant differences in the interactions.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training acceleration and post-training acceleration between the trained-group and the placebo group at each second. A marginally significant difference was found in the 1st second ($t[34] = -1.916, p = .064$).
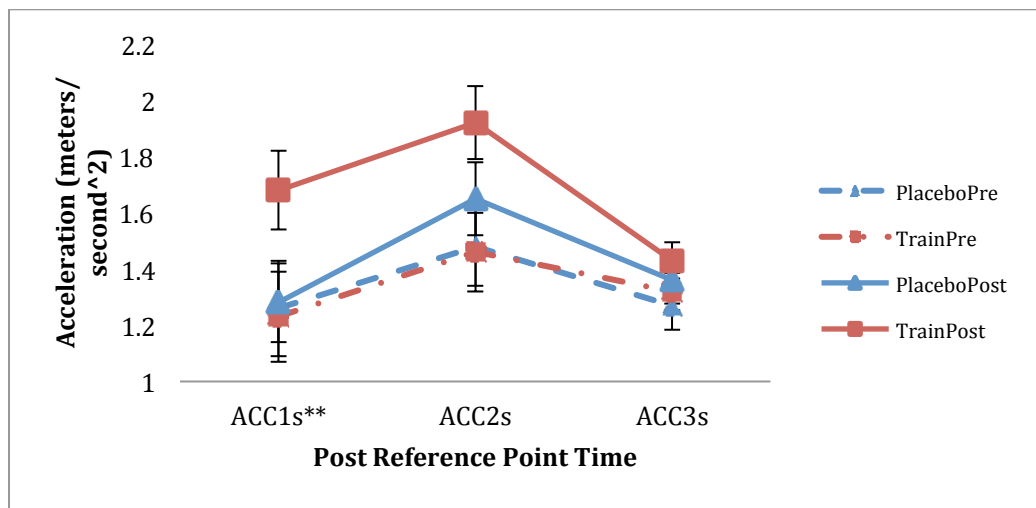
Figure 17. Changes in acceleration over 3 seconds from the reference point
(** - Marginal significance in the difference score between pre and post-training drive)

Figure 18 displays the changes in throttle position (unit: degrees) over 3 seconds from the reference point. There was significant difference in the main effect of the Time from Reference Point ($F[2] = 55.217, p < .001$). A backward elimination procedure revealed no significant differences in the interactions. A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference

score between the pre-training throttle position and post-training throttle position between the trained-group and the placebo group at each second. No significant differences were found.
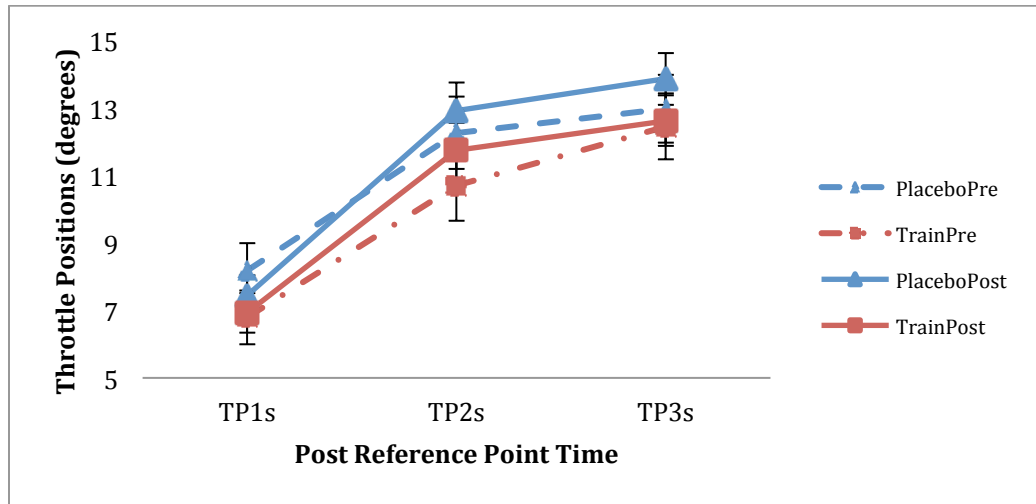
Figure 18. Changes in throttle position over 3 seconds from the reference point

In summary, the participants in the LAG training group had a slower initial speed. Because of this, the participants in the LAG training group had a larger acceleration rate in the 1st second, but still, they were able to maintain a slower speed during the 1st second.

4.2.2 Near Transfer Scenario 2

In the Near Transfer Scenario 2 (Figure 2), the participants came to a stop sign controlled T-intersection and were asked to turn right. There was cross traffic approach from the left, but not the right. The participants view to the right was blocked until participants reached the intersection. Hypothetically, the participants in the trained group would have more glances towards the target zone. The participants in the trained group would accelerate less quickly than the participants in the placebo group.

In this scenario, the zone towards which the driver had to glance (the target zone) was defined as the area that was to the right of the intersection, where the participants had no clear vision. The zone in which the drivers had to launch a glance (the launch zone) was defined as the area that was anywhere between 2 meters upstream of the stop sign and the stop sign itself. The dependent variable derived from an analysis of eye movements was whether the participants looked to the target zone when they were at the launch zone (1 – the participant looked to the target zone when at the launch zone; 0 – otherwise). Due to the fact that in the pre-training drive, none of the participants in the placebo group, nor in the trained group, looked to the right, a chi-square test was conducted for the post-training drive only to explore the percentage of looking to the target zone between the two groups. A significant difference was found $(\chi_1^2 = 32.211, p < .001)$; the participants in the trained group were more likely to look to the right (Mean = .94, unit: %, SE = .056) than the participants in the placebo group (Mean = 0, SE = 0).

In the Near Transfer Scenario 2, the participants legally had to stop due to the presence of a stop sign. No participants were observed who rolled through the stop sign. In this case the *reference point* was defined as the time when the participants first started accelerating after slowing to a stop. The changes in average velocity (unit: meters/second) during the 1st, the 2nd, and the 3rd second from the reference point are shown below in Figure 19. There was a significant main effect of the Time from Reference Point $(F[2] = 163.900, p < .001)$. A backward elimination procedure revealed a significant difference in the interaction between the Training Condition and the Pre/Post Status $(F[1] = 9.724, p = .002)$.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training velocity and post-training velocity between the trained-group and the placebo group at each second. There were significant differences in the 2nd second $(t[34] = -2.076, p = .046)$, in the 3rd second $(t[34] = -2.214, p = .034)$, and a marginally significant difference in the 1st second after the participants started accelerating $(t[34] = -1.809, p = .079)$. In addition, across all the 3 seconds, there was no significant difference between the trained group and the placebo group in the pre-training drive, or in the post-training drive. In other words, over the 3 seconds, the participants in the placebo group were driving slower in the post-training drive than in the pre-training drive, while the participants in the trained group were driving slower in the pre-training drive as in the post-training drive. These are not the results which were expected. However, if drivers in the training group were more aware of cross traffic, bicyclists or pedestrians which could quickly emerge from the right, then, assuming that they glanced in that direction, they would want to enter traffic more quickly.
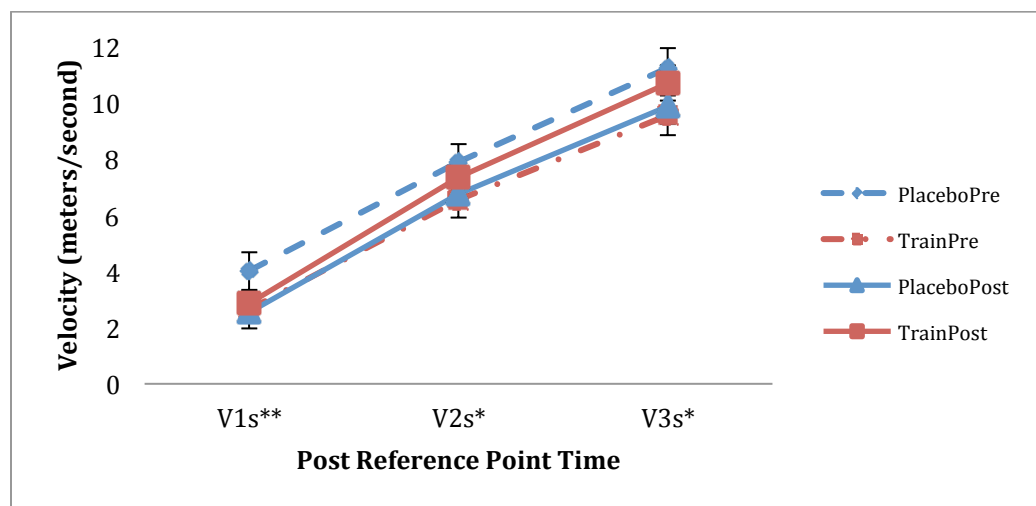

Figure 19. Changes in velocity over 3 seconds from the reference point
(* - significance in the interaction, ** - marginal significance in the interaction)

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Figure 20 displays the changes in acceleration (unit: meters/second²) over 3 seconds from the reference point. There was a significant difference in the main effect of the Time from Reference Point $(F[2] = 8.556, p < .001)$, and a marginally significant difference in the Pre/Post Status $(F[1] = 3.418, p = .066)$. A backward elimination procedure revealed no significant differences in the interactions.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training acceleration and post-training acceleration between the trained-group and the placebo group at each second. No significant difference was found. However, the trend has indicated that in the post-training drive, the participants in the trained group tended to accelerate more quickly than the participants in the placebo group in the 1st second.
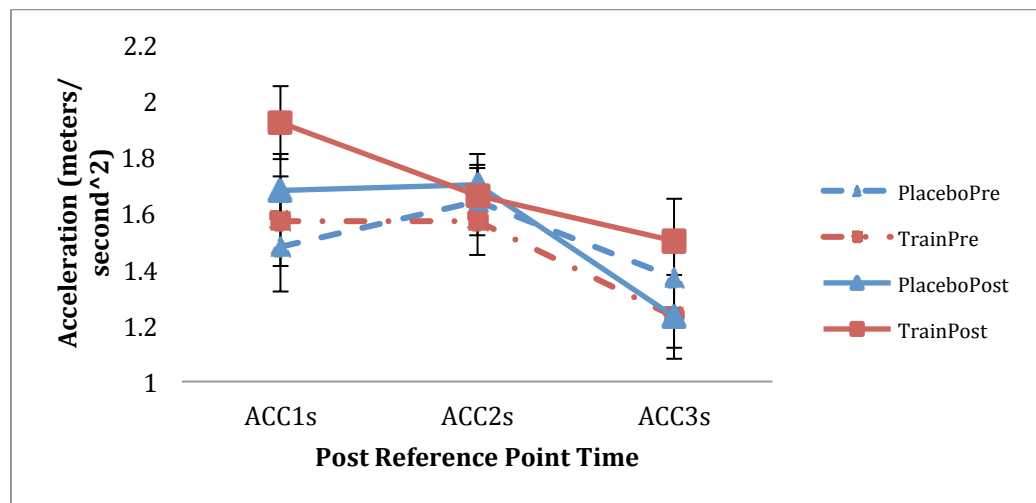

Figure 20. Changes in acceleration over 3 seconds from the reference point

A similar analysis was conducted on the throttle position over the same period of time, shown in Figure 21. A significant difference was found in the main effect of the Time from Reference Point $(F[2] = 16.404, p < .001)$. There was no significant

difference found in the main effects or in the interactions. A backward elimination procedure was conducted in order to further explore the interactions. There was a significant difference in the interaction between the Training Condition and the Pre/Post Status ($F[1] = 5.303, p = .022$).

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training throttle position and post-training throttle position between the trained-group and the placebo group at each second. No significant difference was found.

The analyses presented above have indicated that the LAG trained participants were driving and accelerating faster in the post-training drive than in the pre-training drive, with more valid glances toward the target zone, while the placebo group participants were driving and accelerating slower in the post-training drive than in the pre-training drive, but had no difference in valid glances toward the target zone.
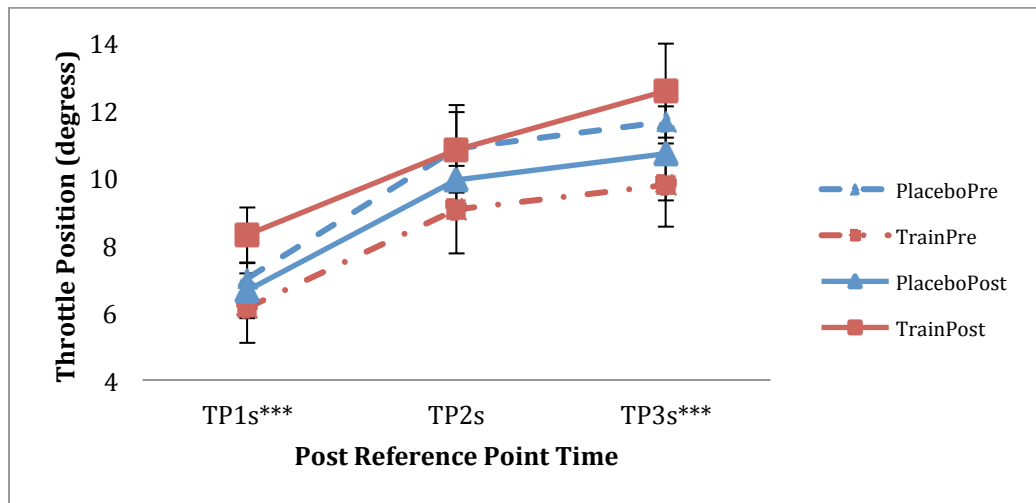

Figure 21. Changes in throttle position over 3 seconds from the reference point

4.2.3 Near Transfer Scenario 3

In the Near Transfer Scenario 3 (Figure 3), the participants came to a crosswalk, with vision to the right blocked by a bus. In this scenario, eye behavior, vehicle speed, acceleration rate, and throttle position were analyzed. Hypothetically, the participants in the trained group were expected to have more glances toward the target zone. The percentage of the participants who slowed down yielding to potential pedestrians in the trained group was expected to be higher the percentage of the placebo group. The participants in the trained group were expected to accelerate less quickly.

For the eye measurement analysis, the target zone was defined as the crosswalk area that was on the right and blocked by the bus, the launch zone was defined as the area that began 2 meters upstream of the crosswalk and ended at the crosswalk. The dependent variable was whether the participants looked to the target zone while they were at the launch zone before accelerating (1 – the participant looked to the target zone while they were at the launch zone; 0 – otherwise). There are significant main effects of Pre/Post Status ($\chi^2_{1_{wald}} = 7.863, p = .005$) and Training Condition ($\chi^2_{1_{wald}} = 7.966, p = .005$). Although the interaction between the Pre/Post Status and the Training Condition was not significant, a pairwise comparison post hoc analysis using a sequential Bonferroni correction indicated that in the post-training drive, the participants in the LAG trained group were more likely to look to the target zone than the participants in the placebo group ($\chi^2_1 = 10.300, p = .001$). There was no significant difference in the pre-training drive between the two groups (Figure 22).

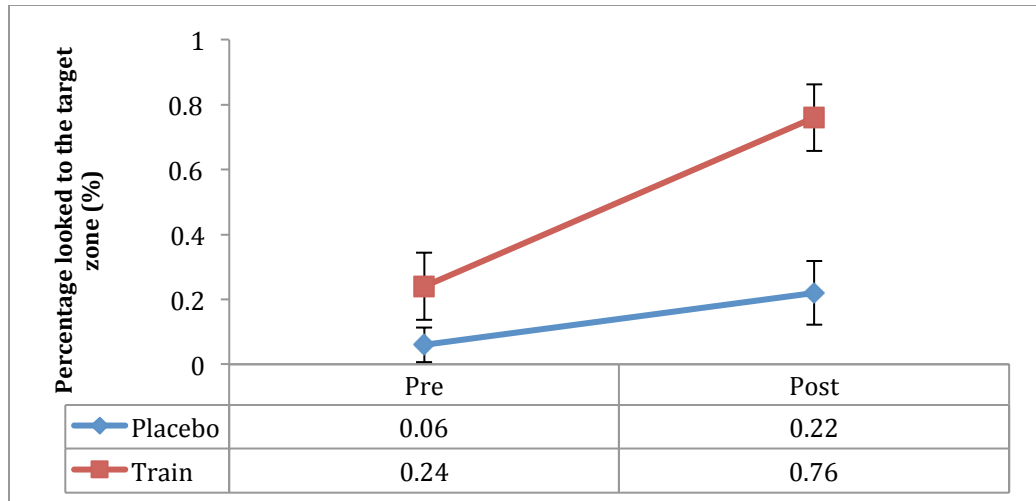|	Pre	Post
Placebo	0.06	0.22
Train	0.24	0.76

Figure 22. Eye measurement – Percentage of participants looked to the target zone

In the Near Transfer Scenario 3, the *reference point* was defined as the time when participants reached their minimum speed. Figure 23 shows the changes in velocity over 3 seconds from the reference point. There were significant differences in all three main effects: the Training Condition $(F[1] = 39.080, p < .001)$, the Pre/Post Status $(F[1] = 28.289, p < .001)$, and the Time from Reference Point $(F[2] = 8.448, p < .001)$. A backward elimination procedure was utilized. A significant difference was found in the interaction between the Training Condition and the Pre/Post Status $(F[1] = 8.547, p = .004)$.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training velocity and post-training velocity between the trained-group and the placebo group at each second. A significant difference was found in the 1st second $(t[33] = 2.198, p = .035)$. A marginally significant difference was found in the 2nd second $(t[33] = 1.852, p = .073)$. Such trend indicates that the difference between the pre- and post-training velocity of the

LAG trained participants are significantly larger than the difference of the placebo group. In the pre-training drive, the participants in the trained group were driving slower than the participants in the placebo group. One can ask why the velocity might be slower here in Near Transfer Scenario 3 for the trained group than the placebo group and faster in Near Transfer Scenario 2 for the trained group than the placebo group. One quick answer is that in this scenario only slow moving pedestrians or bicyclists pose a threat. In Near Transfer Scenario 2, fast moving cross traffic poses a threat. In the former case, it is safest for the driver to accelerate slowly. In the latter case, it is safest for the driver to accelerate more quickly.
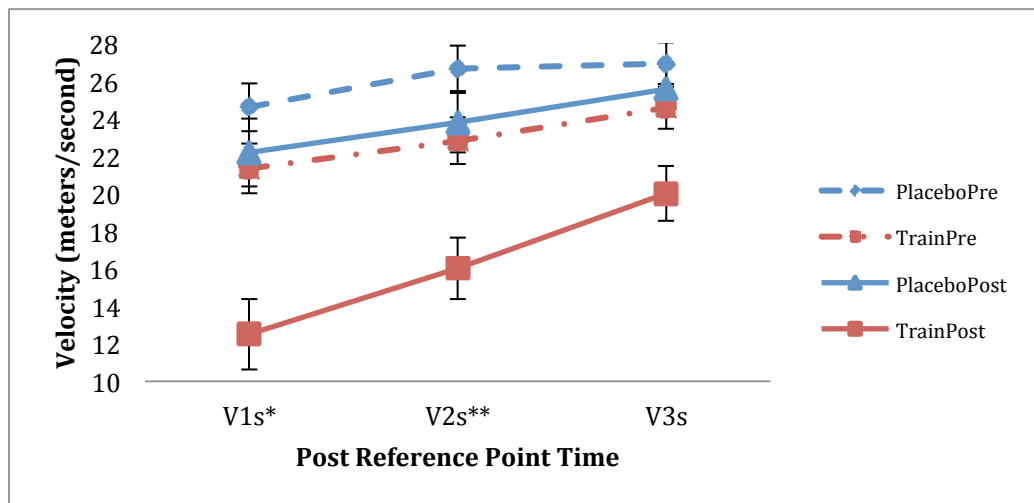
Figure 23. Changes in velocity over 3 seconds from the reference point
(* - significance in the interaction, ** - marginal significance in the interaction)

Figure 24 displays the changes in acceleration over 3 seconds from the reference point. There were significant differences in all three main effects: the Training Condition $(F[1] = 21.743, p < .001)$, the Pre/Post Status $(F[1] = 37.648, p < .001)$, and the Time from Reference Point $(F[2] = 7.145, p = .001)$. A backward elimination

procedure revealed a significant difference in the interaction between the Training Condition and the Pre/Post Status $(F[1] = 13.144, p < .001)$.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training acceleration and post-training acceleration between the trained-group and the placebo group at each second. A significant difference was found in the 2nd second $(t[33] = -2.102, p = .043)$, and in the 3rd second $(t[33] = -2.398, p = .022)$. No significant difference was found in the 1st second. The trend of acceleration indicates that in the post-training drive, while the participants in the trained group reached a smaller velocity, when they tended to accelerate to a normal travel speed, they were able to accelerate as smoothly as the participants in the placebo group during the 1st second, who had already travel at a constant speed and required no acceleration.
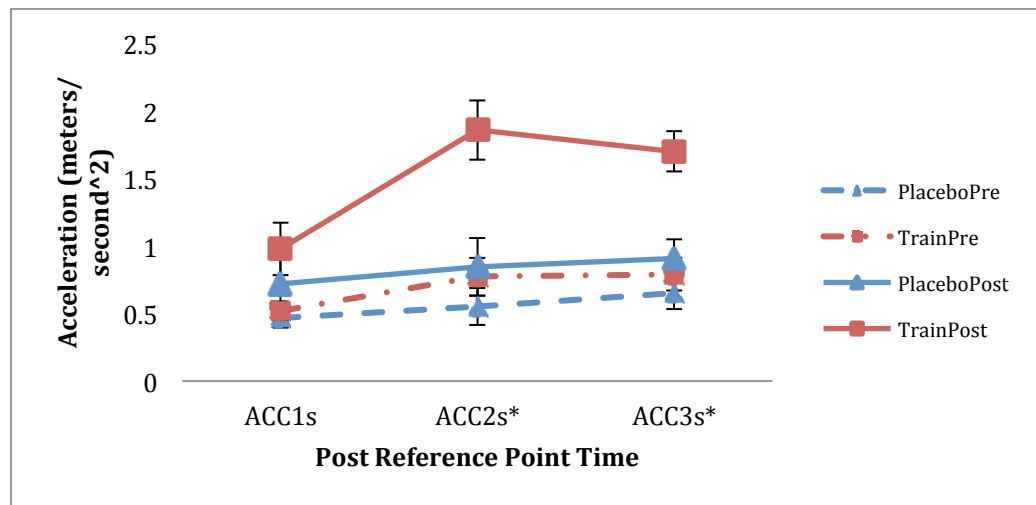

Figure 24. Changes in acceleration over 3 seconds from the reference point

Figure 25 displays the results of the analysis of the throttle position. There were significant differences in the main effects of the Time from Reference Point $(F[2] =$

24.882, $p < .001$), and the Pre/Post Status ($F[1] = 15.952, p < .001$). In addition, the analysis revealed significant interactions in all 2nd order of interactions: the Training Condition and the Pre/Post Status ($F[1] = 4.334, p = .039$), the Training Condition and the Time from Reference Point ($F[2] = 3.135, p = .047$), the Pre/Post Status and the Time from Reference Point ($F[2] = 4.050, p = .020$). A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted. A marginally significant difference was found in the 2nd second ($t[33] = -2.054, p = .048$), and a significant difference was found in the 3rd second ($t[33] = -2.835, p = .008$). Notice that the difference score in the 1st second is not significant. If combined together with the changes in the velocity analysis (Figure 23), it can be concluded that larger increase in throttle position across the first three seconds is due to the fact that the LAG trained participants were travelling much slower the 1st second. At the end of the third second they were still traveling 5 m/s slower than the placebo trained group.
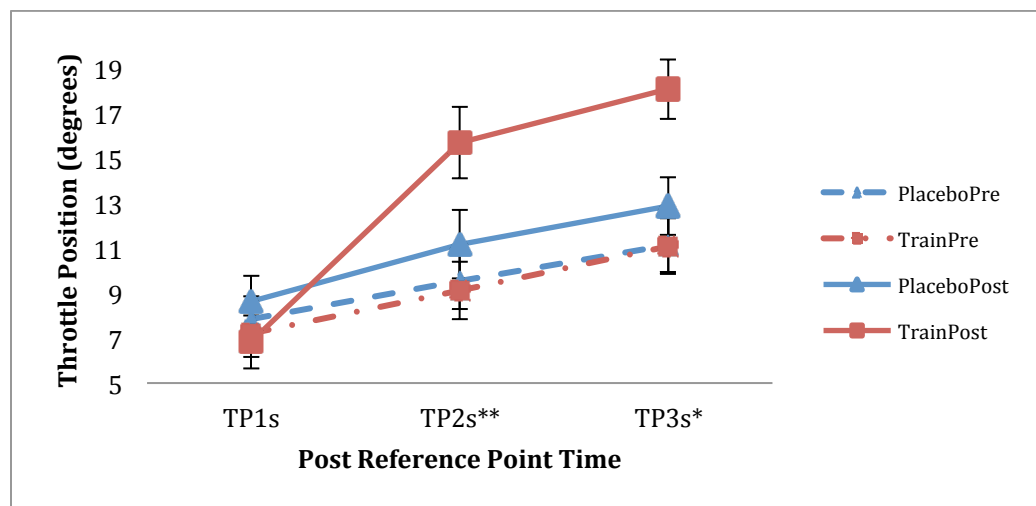

Figure 25. Changes in throttle position over 3 seconds from the reference point

4.2.4 Far Transfer Scenario A

In the Far Transfer Scenario A (Figure 4), the participants came to a stop sign controlled 4-way intersection and were intending to continue straight. Cross traffic had the right of the way and the participants' view to the left and right were blocked. Two target zones were defined in this scenario. Hypothetically, the participants in the trained group would have more glances to both two target zones than the participants in the placebo group. The participants in the trained group would accelerate less quickly.

Target zone I was defined as the area to the left of the intersection that participants had no clear vision to. Target zone II was defined as the area to the right of the intersection that participants had no clear vision to. The launch zone was the same for the target zone I and target zone II, which was the area that was anywhere between 2 meters upstream of the stop sign and the stop sign itself. The dependent variables of the eye measurements in this scenarios were: 1) whether the participants glanced to the target zone I while they were at the launch zone (1 – they looked to the target zone while at the launch zone, 0 – they did not); 2) whether the participants glanced to the target zone II while they were at the launch zone (1 – they looked to the target zone II while they were at the launch zone, 0 – they did not).

For the dependent variable associated with target zone I (whether participants glanced to the left), there was a significant difference of main effect Pre/Post Status ($\chi^2_{1_{wald}} = 22.939, p < .001$), and a marginal significant difference in the interaction between the two main effects ($\chi^2_{1_{wald}} = 2.887, p = .089$). A pairwise comparison post hoc analysis using a sequential Bonferroni correction revealed but no significant

difference between the LAG trained group and the placebo group in the post-training drive, nor in the pre-training drive (Figure 26).

For the dependent variable associated with target zone II (whether participants glanced to the right), there was a significant difference of main effect Pre/Post Status ($\chi^2_{1_{wald}} = 14.284, p < .001$). A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted. In the post-training drive, the percentage of the participants in the LAG trained group that glanced to the target zone II was significantly larger than the percentage of the participants in the placebo group ($\chi^2_1 = 5.461, p = .019$), shown in Figure 27.

	Pre	Post
Placebo	0.22	0.67
Train	0.06	0.78

	Pre	Post
Placebo	0.06	0.28
Train	0.06	0.67
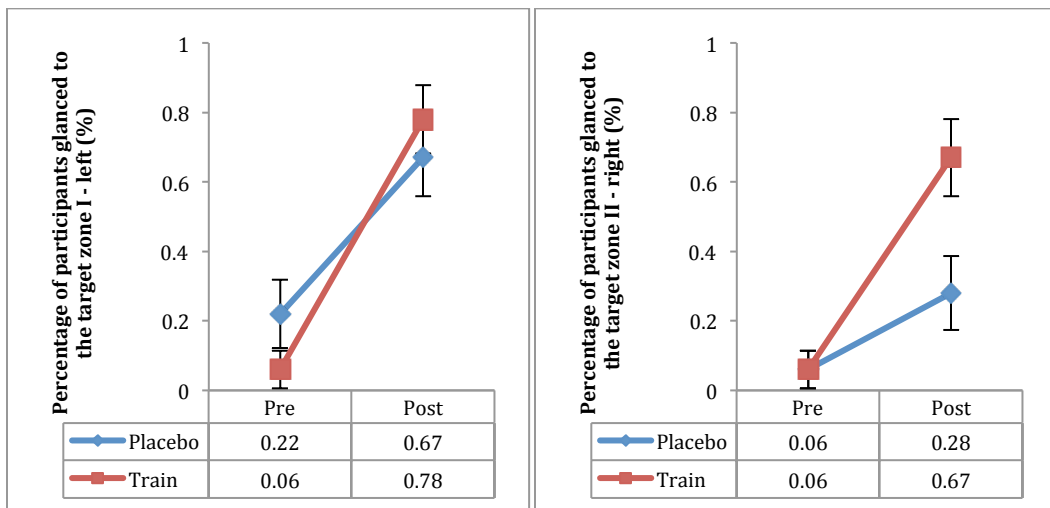
Figure 26. Target zone I performance   Figure 27. Target zone II performance

In Far Transfer Scenario A, the *reference point* was defined as the time when the participants first accelerating to cross the intersection after they fully stopped at the intersection. The changes of acceleration and throttle position over the 3 seconds from the reference point were displayed in Figure 29 and **Error! Reference source not found.** respectively.

For the acceleration, there were significant main effects of the Time from Reference Point $(F[2] = 30.830, p < .001)$, and the Pre/Post Status $(F[1] = 43.621, p < .001)$. There was also a significant difference in the 2nd order of interaction between the Training Condition and the Pre/Post Status $(F[1] = 8.373, p = .004)$.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was performed to explore the difference score between the pre-training acceleration and post-training acceleration between the trained-group and the placebo group at each second. There was a marginal significant difference in 2nd second $(t[32] = -2.032, p = .051)$, and in the 3rd second $(t[32] = -1.852, p = .073)$. The trend of the changes in acceleration showed that after receiving the training, the participants in the trained group were likely to accelerate more quickly than the participants in the placebo group.
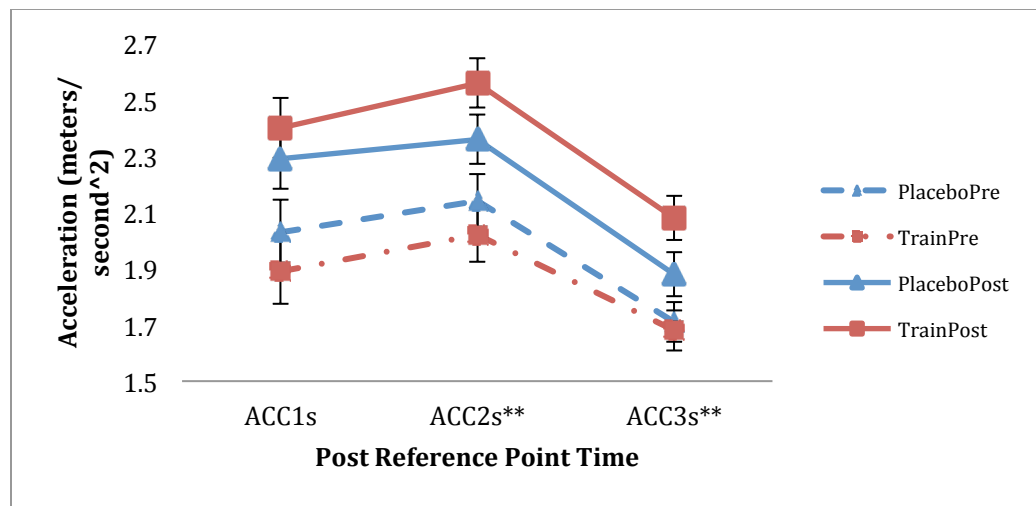

Figure 28. Changes in acceleration over 3 seconds from the reference point
(** - marginal significance in the difference score between trained and placebo group)

In the throttle position analyses, there were significant differences in the main effects of the Time from Reference Point ($F[2] = 72.981, p < .001$), the Pre/Post Status ($F[1] = 41.684, p < .001$), and a marginally significant difference in the Training Condition ($F[1] = 3.168, p = .077$). In addition, a significant difference was in the 2nd order of interaction between the Training Condition and the Pre/Post Status ($F[1] = 5.187, p = .024$).

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training throttle position and post-training throttle position between the trained-group and the placebo group at each second. No significant difference was found. Similar to the trend of the changes in acceleration, the trend indicated that in the post-training drive, the participants in the train group tended to have a wider throttle position than the participants in the placebo group. Although this not aligned with what was expected, one explanation is that after scanning the surrounding environment, the participants who received the LAG training were sure that no potential hazards would emerge, thus they would like to drive through the scenario as fast as possible in order not to miss the safe gap.
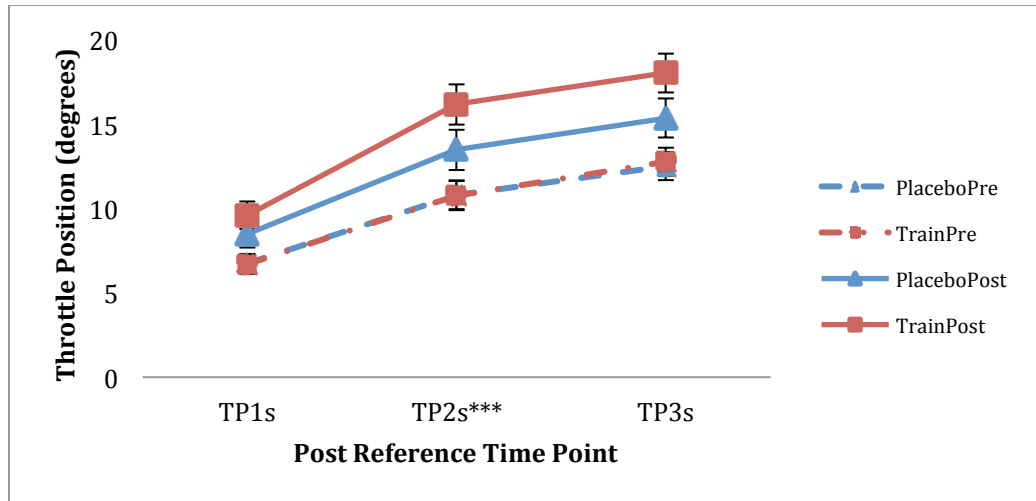
Figure 29. Changes in throttle position over 3 seconds from the reference point

4.2.5 Far Transfer Scenario B

In the Far Transfer Scenario B (Figure 5), the participants came to a stop sign controlled 4-way intersection and were intending to continue straight. Vehicles on the cross direction had the right of the way and were coming toward the intersection from the left with different lengths of gaps. Hypothetically, the participants in the trained group would have more glances to the target zone than the participants in the placebo group. The participants in the trained group would accelerate less quickly. The *reference point* in this scenario was defined as the time when the participants first started accelerating. For the eye measurement analysis, the target zone was defined as the area to the right of the intersection that participants had no clear vision to. The launch zone was defined as the area that was anywhere between 2 meters upstream of the stop sign and the stop sign itself. The dependent variable was whether the participants looked to the target zone when they were in the launch zone (1 – the participant looked to the target zone when they were in the launch zone; 0 – otherwise). A significant difference was found in the

main effect of Pre/Post Status ($\chi^2_{1_{wald}} = 14.111, p < .001$). A pairwise comparison post hoc analysis using a sequential Bonferroni correction revealed a significant difference in the interaction between the Pre/Post Status and the Training Condition ($\chi^2_{1_{wald}} = 5.459, p = .019$). In the post-training drive, the LAG trained participants were significantly more likely to glance to the target zone than the participants in the placebo group ($\chi^2_1 = 5.903, p = .015$). There was no significant difference in the pre-training drive (Figure 30).

	Pre	Post
Placebo	0.17	0.33
Train	0.06	0.75
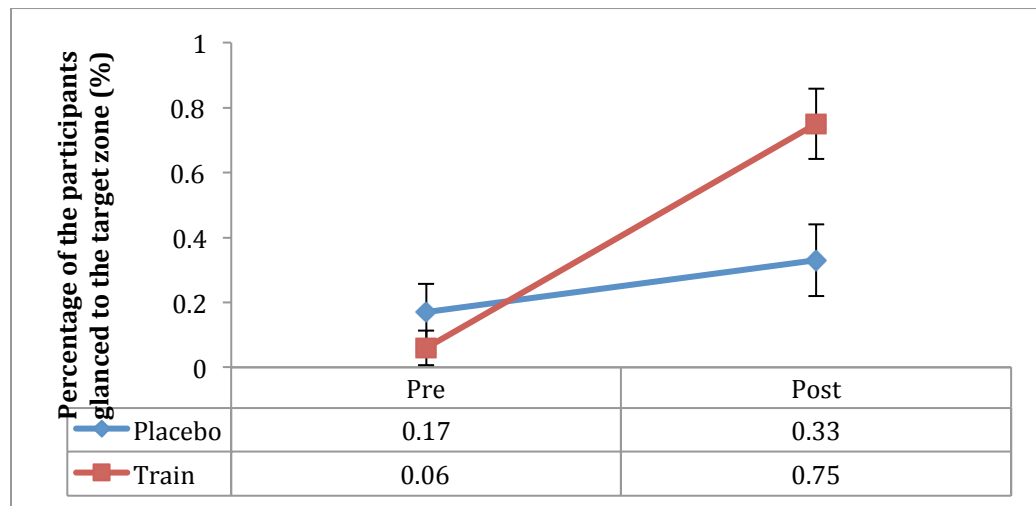
Figure 30. Percentage of the participants glanced to the target zone

The changes of the acceleration within the 3 seconds from the reference point were analyzed to explore the participants' acceleration behaviors (Figure 31). There were significant difference in the main effects of the Training Condition ($F[1] = 6.659, p = .011$), the Time from Reference Point ($F[2] = 30.316, p < .001$), and a marginally significant difference in the Pre/Post Status ($F[1] = 3.567, p = .061$). A backward elimination procedure was performed to further investigate the interactions. No significant difference was found.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was performed to explore the difference score between the pre-training acceleration and post-training acceleration between the trained-group and the placebo group at each second. No significant difference was found. The trend, however, indicates that the participants who received the LAG training program were likely to accelerate faster than the participants in the placebo group.
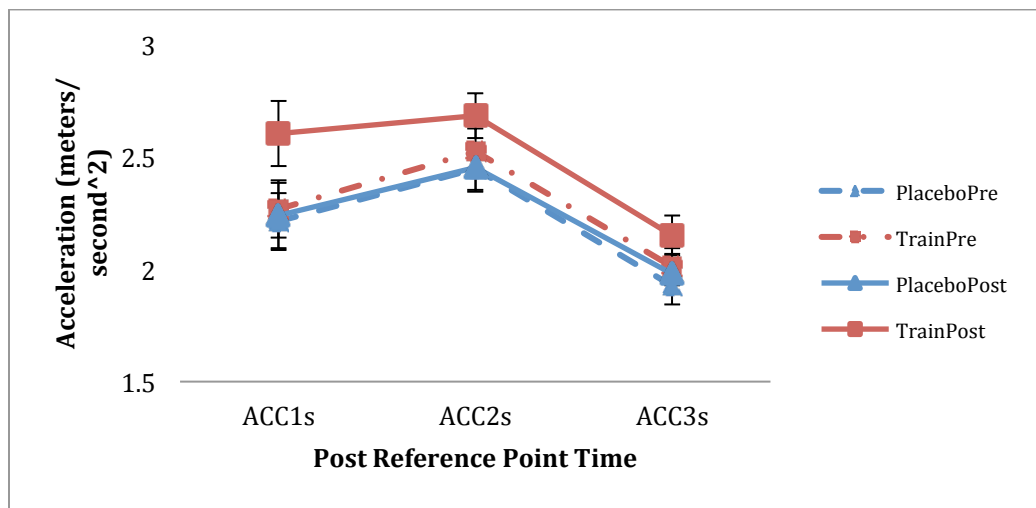
Figure 31. Changes in acceleration over 3 seconds from the reference point

The changes in throttle position within the same period were analyzed as well. The results are displayed in Figure 32. There were significant differences in all three main effects: the Training Condition $(F[1] = 8.769, p = .003)$, the Pre/Post Status $(F[1] = 5.731, p = .018)$, and the Time from Reference Point $(F[2] = 40.804, p < .001)$. There was a significant in the 2nd order interaction between the Training Condition and the Pre/Post Status $(F[1] = 5.335, p = .022)$.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training throttle position

and post-training throttle position between the trained-group and the placebo group at each second. There was a marginally significant difference in the 2nd second ($t[34] = -1.774, p = .085$). The trend, similar to the trend of changes in acceleration, shows that after receiving the LAG training program, the participants in the trained group tended to have a larger throttle position than the participants in the placebo group. Such trends are consistent with the results from Far Transfer Scenario A, which again proved that when being aware of the surrounding environment and the time was limited, the participants who received the LAG training program would like to accelerate quickly in order to drive from the potential hazards as fast as possible. The participants in the placebo group, on the other hand, were less aware of the where potential hazards could emerge therefore did not have the time pressure and behaved as usual.
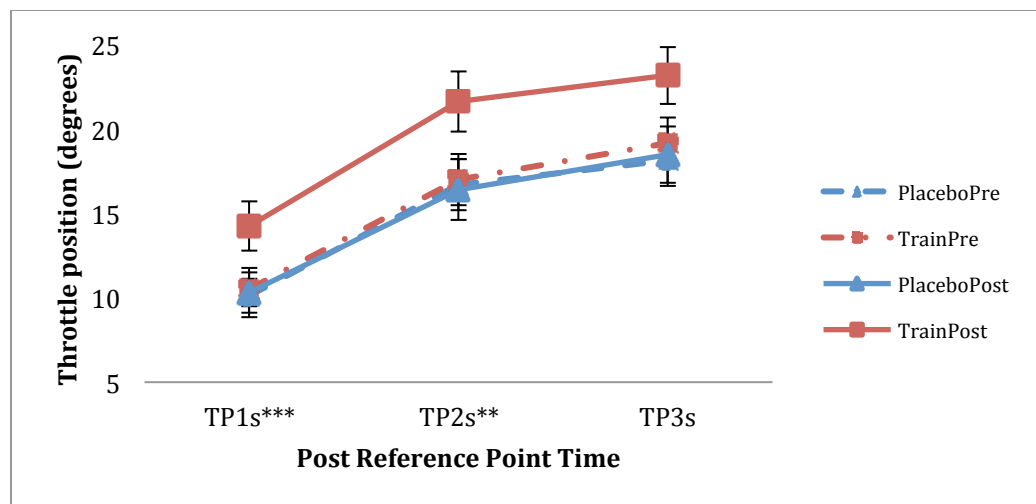

Figure 32. Changes in throttle position over 3 seconds from the reference point (** - marginal significance in the interaction; *** - significant trend in the interaction)

4.2.6 Far Transfer Scenario C

In the Far Transfer Scenario C (Figure 6), the participants came to a signalized 4-way intersection. The light turned from green to yellow 2-3 seconds before the participants arrived at the intersection. A dependent variable, defined as whether the participants beat light and cross the intersection (1 – crossed the intersection, 0 – otherwise), was analyzed. The results are shown in Figure 33. There was no significant difference in the main effects, or in the interaction.

	Pre	Post
Placebo	0.67	0.56
Train	0.61	0.61
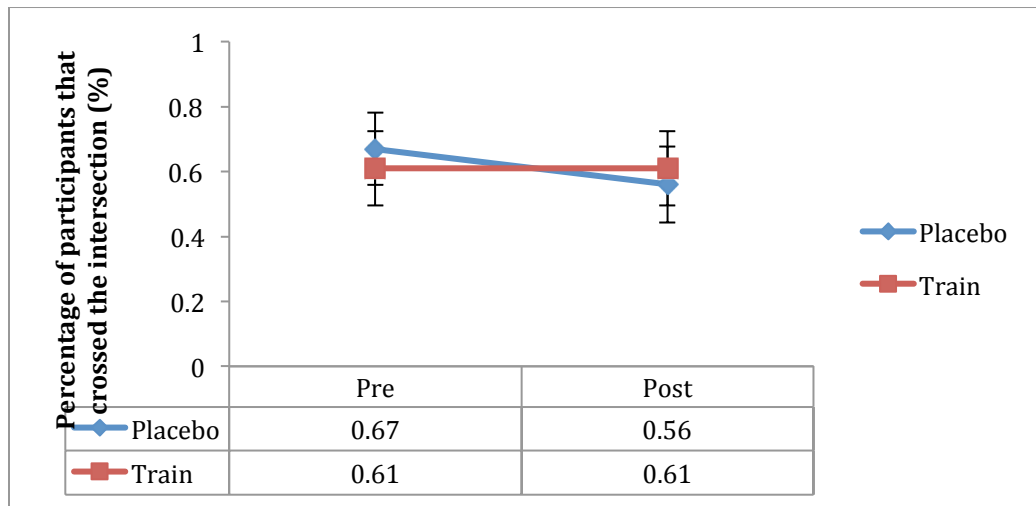
Figure 33. Percentage of participants crossed the intersection

4.2.7 Far Transfer Scenario D

In the Far Transfer Scenario D (Figure 7), the participants came to a signalized 4-way intersection with red light and were intending to go straight. The participants' view to the left was blocked by a truck that stopped in the dedicated left lane. Hypothetically, the participants in the trained group would have more glances to the target zone than the participants in the placebo group. The participants in the trained group would accelerate less quickly. The *reference point* was the time when the participants first started

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accelerating when the light turned into green. The target zone of the eye measurement analysis was defined as the area to the left of the intersection that was blocked by the truck. The launch zone of the eye measurement analysis was defined as the area that was anywhere between 1.5 meters upstream of the traffic light. The dependent variable was whether the participants looked to the target zone when they were at the launch zone, after the traffic light turned into green (1 – the participants looked to the target zone when they were at the launch zone; 0 – otherwise). The analysis revealed a significant difference in the main effect of Pre/Post Status ($\chi^2_{1_{wald}} = 11.244, p = .001$). A pairwise comparison post hoc analysis using a sequential Bonferroni correction revealed a significant difference in the interaction between the Pre/Post Status and the Training Condition ($\chi^2_{1_{wald}} = 5.795, p = .016$), shown in Figure 34. In the post-training drive, the percentage of the participants in the trained group that looked to the target zone was significantly larger ($\chi^2_1 = 4.208, p = .04$) than the percentage in the placebo group.

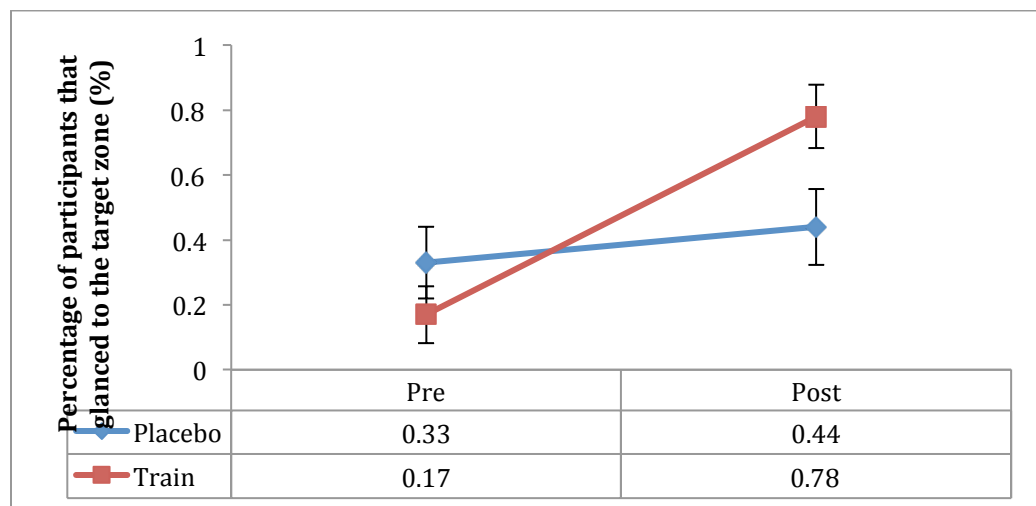|	Pre	Post
Placebo	0.33	0.44
Train	0.17	0.78

Figure 34. Percentage of the participants glanced to the left

Figure 35 displays the results of the changes in acceleration over the 3 seconds from the reference point. There were significant differences in the main effects of the Time from Reference Point $(F[2] = 4.071, p = .019)$, and the Pre/Post Status $(F[1] = 6.453, p = .012)$. A backward elimination procedure was conducted and found no significant differences in the interactions.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training acceleration and post-training acceleration between the trained-group and the placebo group at each second. No significant differences were found. Such results indicate that the participants in the LAG trained group managed to accelerate as smoothly as the participants in the placebo group, while having more glances to the target zone to check out the potential hazards.
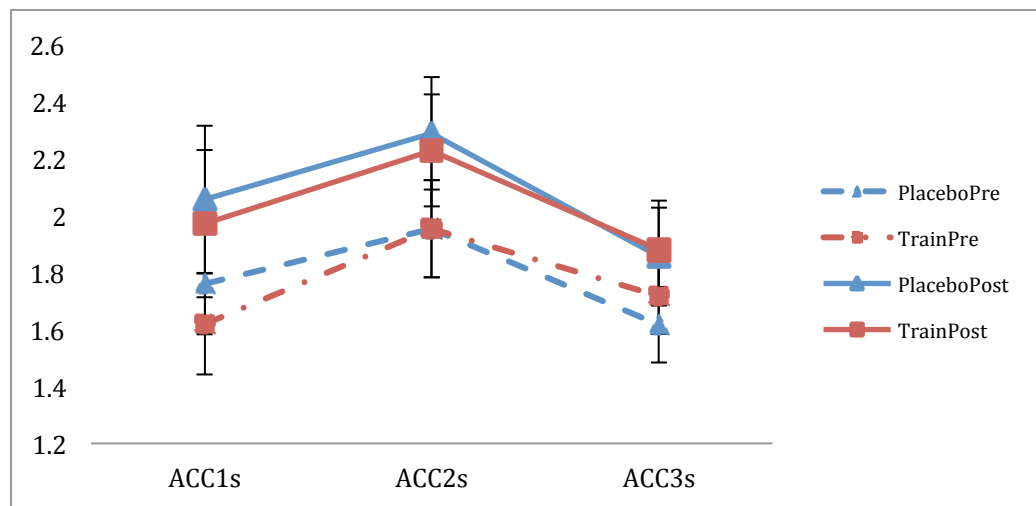

Figure 35. Changes in acceleration over 3 seconds from the reference point

The results of the changes in throttle position are displayed in Figure 36. There were significant differences in the main effects of the Time from Reference Point

$(F[2] = 34.790, p < .001)$, and the Pre/Post Status $(F[1] = 17.195, p < .001)$. A backward elimination procedure was conducted and found no significant differences in the interactions.

A pairwise comparison post hoc analysis using a sequential Bonferroni correction was conducted to explore the difference score between the pre-training throttle position and post-training throttle position between the trained-group and the placebo group at each second. No significant differences were found. This is consistent with the trend of the acceleration.
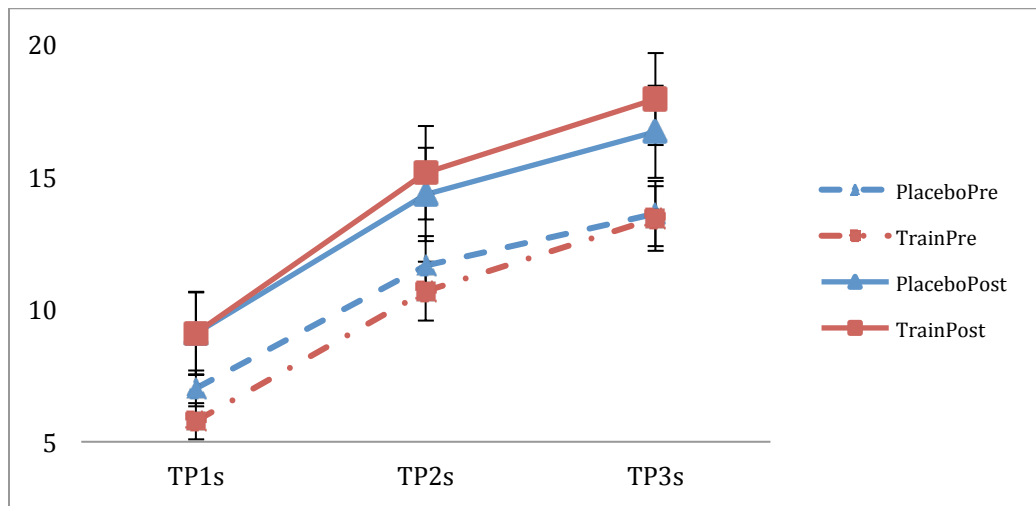

Figure 36. Changes in throttle position over 3 seconds from the reference point

CHAPTER 5

DISSCUSSION

Teen drivers are exposed in a higher crash risk than experienced drivers, and previous studies have shown a positive correlation between quick acceleration and quick deceleration behaviors, and crash risk (Simons-Morton et al., 2012). With this in mind, I developed the Less Aggressive training program (LAG) that was expected to help reduce teen drivers' aggressive driving behaviors, specifically quick accelerations and quick decelerations. I applied active training and error learning to the LAG training program, and evaluated the effectiveness of the LAG training program using a driving simulator. My general hypothesis was that the participants who received the LAG training program would be driving more defensively as they would have fewer unsafe quick acceleration and unnecessary quick deceleration behaviors, and more appropriate glances to the surrounding environment to search for the potential hazards.

On one hand, the results of eye measurement analyses are aligned with the hypothesis in all conditions. Both in the quick deceleration and quick acceleration scenarios, the participants who received the LAG training program were more aware of the potential hazards as they had more valid glances to the target zones where potential hazards would occur. Such results indicate that the LAG training program is effective in training the teen drivers to identify the potential hazards, which is a pre-requisite skill to reduce aggressive driving.

The results of the driving behaviors, on the other hand, are more complicated and varied in different conditions. The details are discussed below by sections.

In the quick deceleration scenario (Near Transfer Scenario 4), the results (Figure 11, Figure 12, Figure 13) are consistent with the hypothesis. The participants who received the LAG training program are considered to be more defensive as they maintained a lower velocity and a larger headway, which allowed the participants to have sufficient time to brake when the lead vehicle suddenly stopped. This has proved the LAG training program to be effective in training teen drivers to reduce unnecessary quick deceleration behaviors, as well as the 3M strategy to be an effective approach in the training program. During the "Mistake" section where LAG trained participants were exposed in dangerous scenarios, all the participants were able to stop in time in the 3-second following distance scenario, only several participants avoid crashing into the lead vehicle in the 2-second following distance scenario, but almost no participants managed to stop in time in the 1-second following distance scenario. This raised the participants' awareness to the contributing factors that caused them into crashes. During the "Mitigation" section, the LAG trained participants were provided with feedback about what the correct behaviors looked like and how to mitigate the hazards. The feedback was given instantly after they were exposed in the hazards, when they still had fresh memories of the hazardous scenarios. Because LAG trained drivers were aware of the potential danger caused by not having a proper following distance, in the evaluation drive, when seeing a lead vehicle, the LAG trained drivers subconsciously lowered their velocity to maintain a larger time headway in case the lead vehicle stopped suddenly.

Quick acceleration evaluation scenarios contained near transfer scenarios and far transfer scenarios. The near transfer scenarios were the scenarios that were designed as similar as to the scenarios given in the LAG training program, while the far transfer scenarios were those that were not identical to the training scenarios but required the same sets of skills. It seems like the results of the quick acceleration scenarios varied from one scenario to another, but if taking a further look at the scenarios, the quick acceleration scenarios can be categorized into two situations based on the scenario type.

In one situation such as Near Transfer Scenario 3 and Far Transfer Scenario D, the potential threat was a pedestrian. In such scenarios, the driver should make sure that the pedestrian does not suddenly emerge by frequently monitoring the pedestrian's behavior and then accelerating slowly. This is exactly what LAG trained participants did and is consistent with the hypothesis. In the Near Transfer Scenario 3, the LAG trained participants took more glances toward the area where a potential hazard would occur, and similarly in Far Transfer Scenario D. However, I did not find any significant difference in terms of the acceleration between the LAG trained group and the placebo group. One possible explanation is that because the acceleration was so small during the first second after the reference point, which the maximum value was $1 \, \text{meters/second}^2$ in the Near Transfer Scenario 3, and $2 \, \text{meters/second}^2$ in the Far Transfer Scenario 4, it is very difficult to detect a difference. This is possible floor effect.

In Near Transfer Scenario 1, Near Transfer Scenario 2, Far Transfer Scenario A, and Far Transfer Scenario B, LAG trained participants had consistently more glances to the potential hazardous areas, however, instead accelerating slowly, the LAG trained

participants accelerated more quickly than the placebo participants during the 1ˢᵗ second after they first started accelerating. This is unexpected. However taking a further look at the scenario types, it is not difficult to find out that the potential threat in these scenarios was a vehicle that had a much faster travelling speed than a walking pedestrian. A driver should first frequently monitor the vehicle behavior and surrounding environment for potential hazards, and then accelerate quickly in order to minimize the exposure time in the middle of the intersections. Here, a quick acceleration was necessary and considered as a safe, defensive driving behavior. Although this is not what was expected before the experiment, the results are consistent with the purpose of the training program, which is to train drivers to first identify situations, and make appropriate choices. In some situations, drivers need to accelerate slowly for the potential pedestrian hazard, and in other situations, drivers need accelerate quickly to avoid vehicle interactions.

An interesting question here is that why LAG trained participants could recognize that they should accelerate quickly in the middle of the intersections but should accelerate slowly for pedestrians. This is because during the "Mitigation" section in the LAG training program, the feedback was customized for each scenario and was given instantly after the participants experienced in the same situation. During the "Mastery" section, the participants were asked to drive the same scenario one more time right after they received the feedback, which gave the participants an opportunity to strengthen what they had learned. This way the participants were able to differentiate among different hazardous scenarios and were able to take actions accordingly.

In the study conducted by Romoser et al. (2012), the results indicated that the number of quick acceleration and deceleration behaviors of the teen drivers were

significantly larger then the number of the adults drivers (Figure 37, **Error! Reference source not found.**Figure 38). One might ask if it is possible that the number of quick acceleration and deceleration behaviors were overrepresented since some of the quick acceleration behaviors are indeed necessary. In this study, the quick acceleration and deceleration behaviors were collected by a device connected via vehicle's OBD-II port without a global positioning system. It is true that the device could net recognize which quick acceleration behaviors are necessary and which are not. However, if in a situation a quick acceleration is needed and necessary, adult experienced drivers should also decide to make a quick acceleration in that particular situation, hence the difference between the teen driver and adult drivers should not be as significant as indicated in the study. The results of the evaluation of the LAG training program has supported this study, that teen drivers in general tend to have more reckless quick acceleration and deceleration behaviors than the adult drivers. The LAG training program has proved to be effective in reducing teen drivers unsafe quick deceleration and unnecessary quick acceleration behaviors.
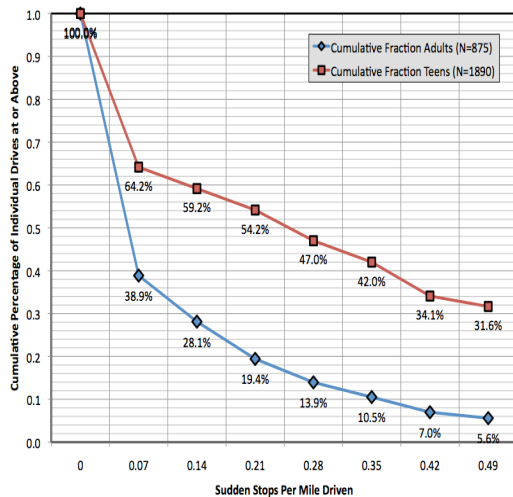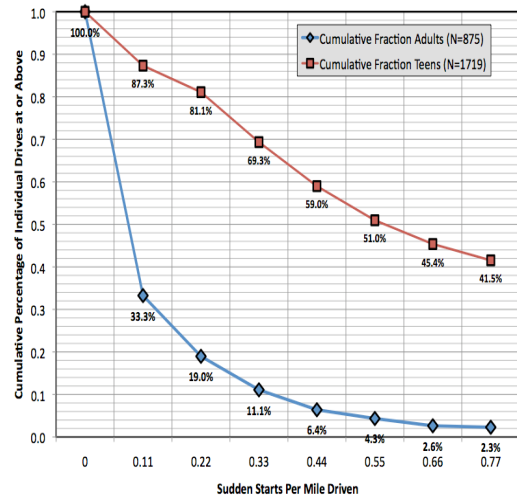

Figure 37. Sudden stops per mile driven   Figure 38. Sudden starts per mile driven

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