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TEEN IVBSS FOT: METHODOLOGY AND RESULTS

MARY LYNN BUONAROSA
SHAN BAO
JAMES R. SAYER

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Mary Lynn Buonarosa

Shan Bao

James R. Sayer

The University of Michigan

Transportation Research Institute

Ann Arbor, Michigan 48109-2150

U.S.A.

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16. Abstract

Given teen drivers' overrepresentation in motor vehicle crashes, a study was conducted to examine whether teens, as a less experienced driver population, might benefit most from an integrated collision warning system. The same integrated warning system had previously been tested with adult drivers, and the intent was to discover whether teens, in particular, would realize greater safety benefits from the integrated crash warning system.

In general, the findings for teen drivers were similar to those for an adult cohort. While some, limited safety positive effects were observed with teens, they were generally comparable to those effects observed with an adult cohort population. The presence of the integrated warning system did have some safety positive effects on lateral control of the vehicle by teen drivers – including a 24% reduction in lane departures and 5-fold increase in turn signal usage when compared to a control group. However, the effects were less pronounced, and of mixed impact, when it came to the longitudinal control of the vehicle. Like their adult cohorts, teens generally offered a favorable impression of the integrated collision warning system.

While some specific safety-positive effects were observed, they were not as prevalent as one might have anticipated or hoped for given teens' overrepresentation in motor vehicle crashes.

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Introduction

Background

In 2008, four thousand fifty-four teenagers died in the United States from injuries sustained in motor vehicle crashes. Such injuries are by far the leading cause of death among U.S. teens 13 to 19 years old. In 2006, 36 percent of all deaths among 16- to 19-year-olds occurred in motor vehicle crashes (Insurance Institute for Highway Safety [IIHS], 2009a). Although they drive less than all but the oldest of drivers, teenage drivers have elevated rates of crashes compared with adult drivers. For crashes of all severities, the crash rate per mile driven for 16- to 19-year-olds is four times as high as the rate for drivers 20 and older (IIHS, 2009b). The rate is highest at age 16, nearly twice as high as for 18- to 19-year-olds.

Fatal crashes of young drivers often occur when other young people are in the vehicle, so teenagers are also disproportionately involved in crashes as passengers; 61 percent of teenage passenger deaths in 2007 occurred in vehicles driven by another teenager. Crash rates for young drivers are high because of their immaturity combined with their inexperience with driving. The crash risk of teenage drivers is particularly high during the first months of licensure (Mayhew, Simpson, and Pak, 2003; McCartt et al., 2003), when their lack of experience behind the wheel makes it difficult for them to recognize and respond to hazards. Immaturity is apparent in young drivers' risky driving practices such as speeding. A study of nonfatal crashes of newly licensed teenage drivers in Connecticut found that important contributing factors were speeding, losing control of the vehicle or sliding, and failing to detect another vehicle or traffic control device, often due to distraction or inattention (Braitman et al., 2008). Teenage crash risk is particularly elevated at night and when carrying teenage passengers (Chen et al., 2000; Doherty et al., 1998; Ferguson et al., 2007; Preusser et al., 1998; Ulmer et al., 1997; Williams, 2003; Williams et al., 2005).

In 2010, the University of Michigan Transportation Research Institute (UMTRI) completed the conduct of a joint Government/Industry/Academia research program entitled Integrated Vehicle-Based Safety System Field Operational Test (IVBSS FOT). The purpose of the Integrated Vehicle-Based Safety Systems (IVBSS) program was to assess the potential safety benefits and driver acceptance associated with a prototype integrated crash warning system designed to address rear-end, roadway departure, and lane change/merge crashes for light vehicles and heavy commercial trucks. A fleet of 16 passenger cars were built with the integrated crash warning system which incorporated the following functions:

- Forward crash warning (FCW): warns drivers of the potential for a rear-end crash with another vehicle;

- Lateral drift warning (LDW): warns drivers that they may be drifting inadvertently from their lane or departing the roadway,
- Lane-change/merge warning (LCM): warns drivers of possible unsafe lateral maneuvers based on adjacent vehicles, or vehicles approaching in adjacent lanes, and includes blind spot monitoring system (BSM).
- Curve speed warning (CSW): warns drivers they are going too fast for an upcoming curve.

If effective, it was estimated that the above systems might have the potential to address 60% of all fatal crashes that occur in the U.S. The key findings from the IVBSS FOT indicated that the integrated crash warning system did provide directly observable benefits. Improvements in lane keeping, fewer lane departures, and increased turn signal use were found. However, there were no directly observable benefits regarding longitudinal control. Drivers were actually slightly more likely to maintain a shorter headway with the integrated system, but there were no obvious negative behavioral adaptation effects observed related to engagement in secondary behaviors. Drivers were generally accepting of the integrated crash warning system, and nearly three-fourths of the drivers reported they would like to have an integrated warning system in their personal vehicles. Drivers reported that the blind-spot detection component of the lane-change/merge crash warning system was the most useful and satisfying aspect of the integrated system.

Relative to crashes where teens are considered to be a fault, the same systems could be capable of addressing 52 percent of all U.S. teen-involved crashes (over 5,000 crashes annually) and 55 percent of all teen fatalities (over 3,000 fatalities annually)—based on 2004 – 2008 FARS and GES statistics for drivers ages 15 to 19 years of age.

Given that teens are highly overrepresented in motor vehicle crashes, the overarching research question for the present study was to determine if teens might benefit, perhaps even more than their adult counterparts, from an integrated collision warning system. Perhaps because teens are not as established in their driving habits as adults, the effect of the warning system in modifying teens' overall driving behavior (headway maintenance, lane keeping, turn signal use, etc.) also warranted investigation.

Methodology

Drivers

Forty teen drivers, in two groups of 20 participants each were randomly assigned to either an experimental or control group, balanced for gender. Teens were recruited from high schools in the vicinity of Ann Arbor, MI. Teens were required to be 16 years old and hold a Level 2 driver's license. Drivers in the experimental group had an average of 6.9 months of driving experience on a Level 2 license while those in the control group had an average of 7.0 months. This level of licensure imposes restrictions on teen driving. With some exceptions, teens are not to drive between 10 PM and 5 AM. Further, they are not to drive with more than one non-family member who is under 21 years of age.

Vehicles and Instrumentation

Twelve of the research vehicles (2006 and 2007 Honda Accord EX sedans) used in the IVBSS program, each equipped with a data acquisition system (DAS), were used. The DAS collected several hundred channels of data (see Sayer, et al, 2008 for a complete description of the DAS and types of collected data) along with substantial video of the scene around the vehicle, and within the driver cabin environment. Three video cameras were located inside the cabin (a face camera video mounted in the A pillar; a camera mounted near the sun roof which provided an "over-the-shoulder look" at the driver; a forward looking camera mounted behind the interior rearview mirror) and two cameras were mounted to the vehicles under each exterior rearview mirror (looking to the areas behind the research vehicle and in the adjacent lane).

The sensor suite for IVBSS consisted of multiple vision, radar, inertial and vehicle sensors.   The integrated warning system included seven radars (one long-range forward-looking 77-GHz radar, two rear-looking mid-range 24-GHz radars, and four side-looking short-range 24-GHz radars); four cameras; non-differential GPS with an onboard digital map; yaw rate gyroscope; and existing OEM vehicle data signals, such as speed, brake switch, and turn signal status. An overview of the sensor coverage is depicted in Figure 1.

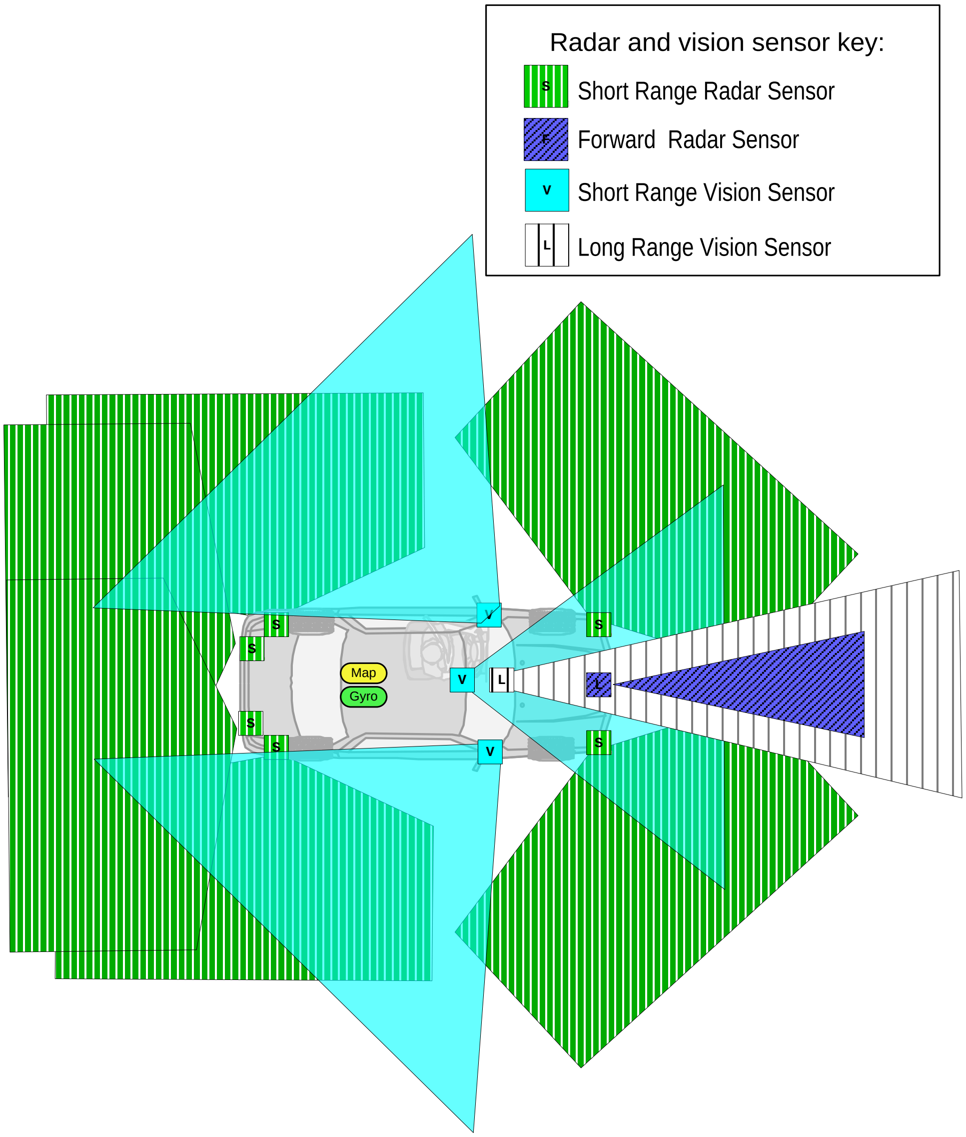


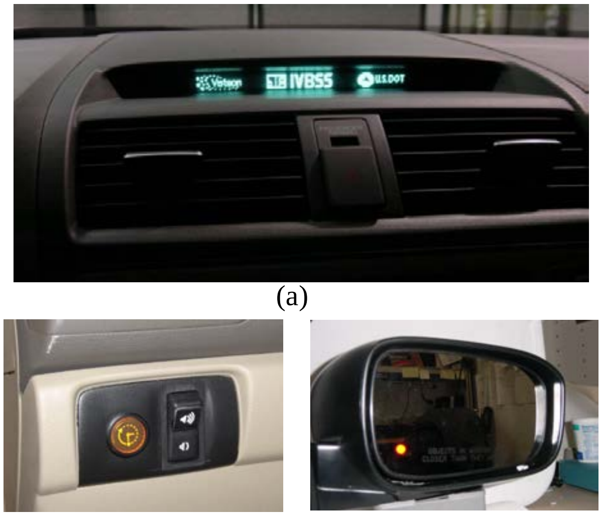
Figure 1: Sensor coverage overview (not to scale)

In addition to the measures from the warning system and the vehicle CAN bus, UMTRI instrumented each research vehicle with a complementary set of sensors that supported and provided additional signals for the analysis phase of the project. These instruments were not part of the system and were installed to provide an independent measure of critical metrics both for the analysis and confirmation of system and vehicle performance. The additional sensors included the following:

- **DGPS**: UMTRI's own differentially corrected GPS module and associated antenna. Measures from this device included latitude, longitude, heading, speed, time and week, number of satellites, and Pdop (percent dilution of position, which is measure of the geometrical strength of the GPS satellite configuration).
- **Yaw Rate**: A stand-alone yaw rate sensor to measure angular velocity. The sensor was ruggedized for transportation applications and had a -60 to 60 deg/s resolution. A routine in the DAS software zeroed the transducer each time the vehicle stopped for at least 60 seconds.
- **Accelerations**: A tri-axial high-precision accelerometer was used to measure longitudinal and lateral accelerations. The unit was mounted near the lateral and longitudinal vehicle mid-point. UMTRI positioned the unit on a rigid cross-member of the frame rail.
- **Steer Angle**: Steer angle was measured by mounting a calibrated string pot to the steering shaft connecting the hand-wheel and steering gear. The string of this analog transducer would wrap or un-wrap around the shaft as the hand-wheel was turned providing a reference voltage to the DAS that was then calibrated to produce an estimate of the actual hand-wheel angle.

Integrated Warning System and Driver-Vehicle Interface (DVI)

The primary modalities for delivering the crash warning information to the teen drivers in the experimental group were auditory and haptic. Imminent crash warnings were presented via a tone delivered in the head restraint while less urgent warnings (e.g., those warnings elicited by a driver drifting into an unoccupied space) were presented as haptic cues in the seat pan. After each warning, a text message was presented in the OEM center-mounted stack to confirm the type of warning. Further, part of the lateral warning system included a blind spot detection system whereby the driver was provided with an illuminated LED in the side view mirror, if a vehicle was in or was approaching the research vehicle's blind spot. While drivers were unable to turn off the system, the DVI also included a mute button, whereby the driver could mute warnings for up to six minutes, as well as a volume control button which provided the driver with three different volume levels for the auditory warnings. The visible physical elements of the driver-vehicle interface are provided in Figure 2.



(a)

(b) (c)

Figure 2: Visible physical elements of the light-vehicle driver interface

The integrated warning system featured four warning types and one driver information feature, as shown in Table 1. For lateral maneuvers, Table 1 shows that drifting without a turn signal applied into a lane or onto a shoulder that is unoccupied is signaled by a haptic seat cue. Drifting into an occupied lane or shoulder is treated with an audible tone meant to be more salient to the driver; an intentional lane change or merging maneuver (i.e., with turn signal applied) into an occupied lane is treated with the same audible tone and visual text display, as shown in Table 1. The same audible tone and text are used because the crash threat is similar and the likely driver responses will likely be similar.

Table 1 also shows that the two longitudinal crash threats (rear-end and curve-speed) are addressed using similar but not identical warnings to the driver. The FCW functionality provides an audible tone and a brake pulse. The CSW provides the same audible tone as FCW, without the brake pulse. The visual text to confirm the meaning of the warnings to the driver is different for these two, as indicated in the table.

Table 1: Crash warning and blind spot detection cues to the driver

Displayed text	**Primary cues to driver**	**Functionality**	**Crash type addressed**
"Hazard ahead"	Audible tone #1, Brake pulse	FCW	Rear-end crash
"Sharp curve"	Audible tone #1	CSW	Curve-overspeed crash
"Left Drift" or "Right Drift"	Seat vibration (directional)	LDW-Cautionary	Lane- or road-departure into an unoccupied lane or shoulder
"Left Hazard" or "Right Hazard"	Audible tone #2 (directional)	LDW-Imminent or LCM	Lane- or road-departure into an occupied lane or shoulder. Lane-change or merging crashes due to changing lanes into an occupied lane.
(None)	LED illuminated in side view mirror	Blind Spot Detection (BSD)	Lane-change or merging crashes.

Experimental Design

Data collection occurred over a 14-month period beginning in July 2011, with each of the 40 teens participating for 14 weeks. The experimental group experienced an ABA design (three weeks baseline, eight weeks treatment, three weeks post-treatment). During baseline and post-treatment periods for the experimental group the research vehicles did not provide any of the crash warning functionality to the driver, but all data as to when a warning would have been presented were collected. While the control group never experienced the integrated crash warning system at all, data were collected continuously—including when a warning would have been presented had the warning system been activated. The IVBSS research vehicles are instrumented to capture information on the driving environment, driver behavior, integrated warning system activity, and vehicle kinematics data. Data, including all video data, were collected at 10 Hz. In addition, subjective data on driver acceptance was collected using surveys.

Prior to beginning participation in the study, each teen in the experimental group participated in a training session which included a video presentation of the integrated crash warning system, an orientation to the research vehicle including a static demonstration of the warnings, and a test drive. Teens in the control group were provided with an orientation to the research vehicle. All of the teens were instructed to use the research vehicle in place of the vehicle that they typically drove. Researchers placed no additional restrictions on their participation and were available 24 hours per day to answer any questions and to address any problems. At the conclusion of the 14-

week participation, teens and one of their parents completed questionnaires about their/their teen's participation. Additionally, teens in the experimental group reviewed approximately 12 video clips from when they received warnings from the integrated crash warning system. They were asked to provide feedback as to the usefulness of receiving a warning in the given situation. Each teen was paid $100 for participating.

Limitations

Six of the thirteen research vehicles did not have operational CSW modules. Therefore, CSWs were not presented to the drivers in these vehicles. Consequently, the CSW analyses that were completed for the adult study were not performed on the teen data. CSW modules also provide data to determine road type information. In the absence of this information, road type was assigned based upon speed. Previously unknown road types were categorized as limited access roads if speeds were in excess of 24.6 m/s. If the speed was below 24.6 m/s, then the road type was categorized as surface streets. Video review of a random sample of clips with unknown road type confirmed that these assumptions were valid in a majority of cases.

The boot-up time for the video cameras varied by research vehicle and took as long as 30 seconds in some vehicles. The range was 1 to 29.9 seconds with a mean of 20.5 seconds. As such, up to the first 30 seconds of vehicle trips are not recorded.

Data Analysis Procedures

There are two types of variables in the data analyses: continuous variables and categorical variables. The analyses of continuous variables (e.g., headway distance, lane offset magnitude, etc.) were performed with linear mixed models using the PROC MIXED procedure. The PROC GLIMMIX procedure was used for the analysis of categorical variables (e.g., turn signal use, etc.). The PROC GENMOD procedure was used when the PROC GLIMMIX procedure failed to converge due to memory limitations. All procedures were conducted in the statistical software package SAS 9.2. Fixed effect predictors included driver group, road type, traffic density, wiper, day/night, exposure period, and driver gender (

Table 2). Driver and interactions between driver and any fixed effects were treated as random effects. This approach accounts for within-subject variance for repeated observations from the same driver, and effectively compares a driver to himself/herself. All the models were built in a stepwise manner by entering the entire candidate variables and removing the non-significant ones one-at-time and iteratively running the models. Interaction between driver group and exposure period were included in all models, even if not statistically significant, in order to isolate the effect of receiving warnings.

Table 2: Fixed variables and their levels

Fixed Effect Predictors	Levels			
Driver group	Control group	Experimental group		
Gender	Male	Female		
Road type	Limited access	Surface road		
Wiper	Off	On		
Day/Night	Day	Night		
Exposure period	Baseline	Treatment	Post-Treatment	
Traffic Density	Sparse	Medium	Dense	

Road type data was provided by NAVTEQ’s advanced driver assistance system (ADAS) map. While the wipers could be operated at different speeds, wiper data was coded as either off or on. Solar angle data provided the information that was used to determine day and night. Night was defined by a solar angle greater than 96 degrees (i.e., when the sun is six degrees below the horizon). The exposure period was divided into three periods: the baseline period was weeks 1 through 3, the treatment period was weeks 4 through 11, and the post-treatment period was weeks 12 through 14. Traffic density was derived from targets acquired by the forward-looking radar unit. In order for a target to be included in a traffic density count, it had to be moving in the same direction as the research vehicle. Targets moving in the same direction as the research vehicle but in lanes to the right or left of the research vehicle were weighted differently than a moving target in front of the research vehicle. Sparse is defined as less than 1.5 vehicles, medium is between 1.5 and 4 vehicles, and dense is greater than or equal to 4 vehicles.

Results

Vehicle Exposure

During the FOT, teens drove 17,248 trips and accrued 100,189 miles. A trip is defined as an ignition cycle (i.e., the time that the ignition is switched on until it is switched off). Of the 17, 248 trips, 15,039 were valid resulting in 93,976 miles representing 3,259 hours of driving. The primary reasons for categorizing a trip as invalid include total trip distance less than 20 m, radar misalignment or malfunctioning, and a fault in either the DAS or the integrated crash warning system.

Teens in the control group accrued more mileage over the course of the FOT, as well as during each of the exposure periods, than their counterparts in the experimental group (54,532 miles versus 39,444 miles respectively, Table 3). Table 4 provides the distribution of valid travel during day and night. About 30% of the mileage was accrued at night.

Table 3: Distance in miles accrued by each driver group by exposure period

Driver Group	**Baseline**	**Treatment**	**Post-Treatment**	**Total**
Control	13,723	29,265	11,544	54,532
Experimental	10,861	22,277	6,307	39,445

Table 4: Distance in miles accrued by each driver group by time of day

Driver Group	**Day**	**Night**	**Total**
Control	37,212	17,320	54,532
Experimental	28,157	11,288	39,445

Crashes

There were a total of seven crashes during the course of the FOT. Six of the crashes occurred in parking lots, parking structures, or driveways. They were low speed and relatively minor crashes. Half of those crashes occurred during a backing maneuver. The only major crash that occurred happened during a control group teen’s commute to school. Just prior to rear-ending the decelerating lead vehicle, the teen had looked away from the forward scene. All the teens involved in crashes were provided with replacement research vehicles and their participation continued in order to achieve 14 weeks of participation for each teen.

Overall Warning Activity

During the FOT, the teens elicited 9,914 warnings. Figure 3 displays a breakdown of the warnings by type. Trained coders reviewed video of every imminent warning (i.e., FCWs, LCMs, and LDW imminent warnings) to determine warning validity. Additionally, 10% of the LDW cautionary warnings were also reviewed. If a warning was elicited in response to a threat, in accordance with the system design, then it was considered valid. A warning was valid even if it did not appear to assist the driver. A warning was invalid if there was no threat present. Table 5 displays the breakdown of valid and invalid warnings by imminent warning type. Figure 4displays the imminent warning rates for the driver groups for each of the exposure periods.

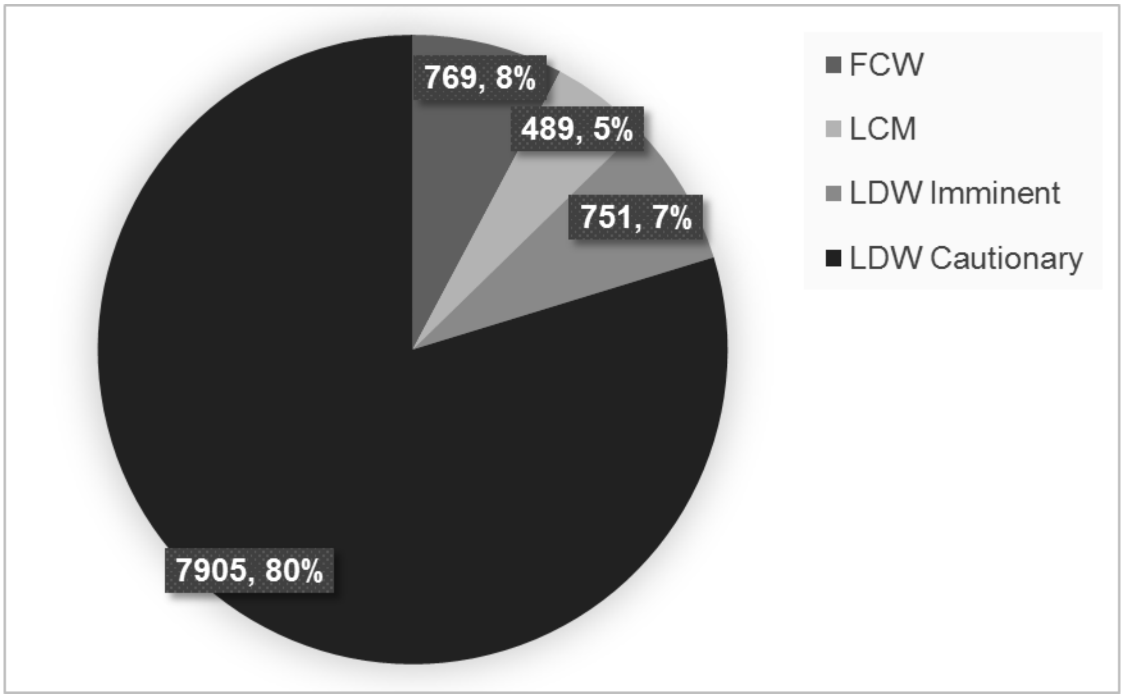


Figure 3: Breakdown of warnings by type

Table 5: Valid and invalid warning counts by imminent warning type

Warning Type	Total warning count	Invalid Warning Count	Percentage of invalid warnings
FCW	740*	376	51%
LCM	485*	49	10%
LDW Imminent	748*	139	19%

*29 FCWs, 4 LCMs, and 3 LDWs could not be analyzed because there was no video associated with the events.

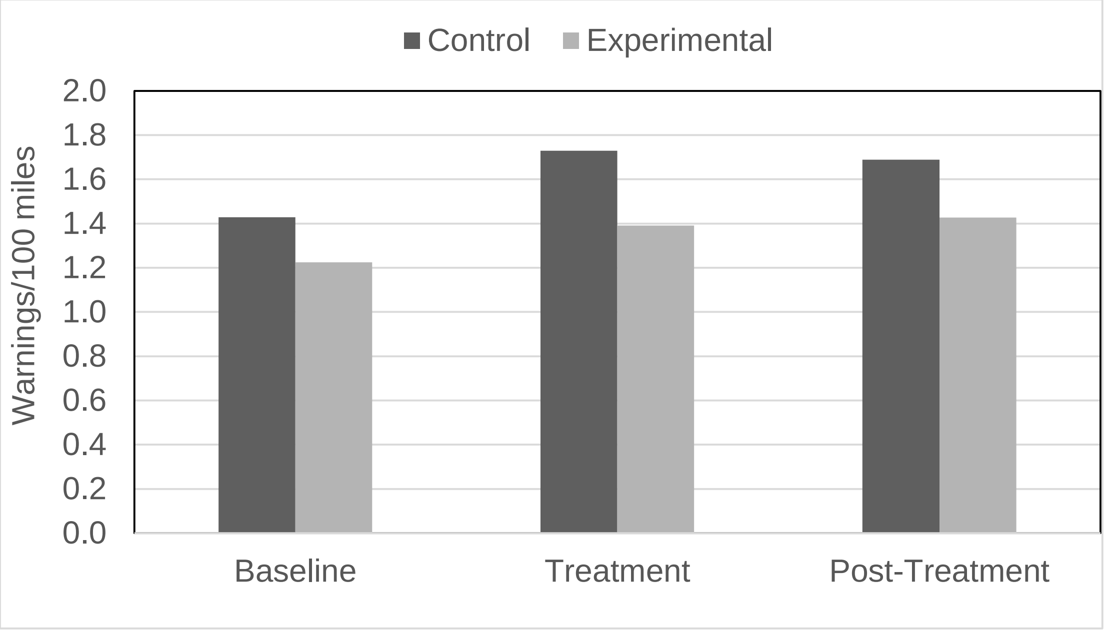


Figure 4: Imminent warning rates for each driver group by exposure period

Research Questions

The following 16 research questions were examined in order to determine the effects of an integrated collision warning system on teen driver behavior. The research questions were determined a priori—having largely been modeled after questions and analyses performed in adult IVBSS FOT study.

QC1: When driving with the integrated crash warning system in the treatment condition will drivers engage in more secondary tasks than in the baseline and post-treatment conditions?

Method: For each of the teen drivers, 32 five-second exposure video clips were selected; 8 each from the baseline and post-treatment periods and 16 from the treatment period. One driver only had 31 eligible clips so the total number of clips that were analyzed was 1,279.

For the baseline sample, video clips were chosen randomly for each driver without regard for the presence of the independent variables (ambient light, wipers, etc.). For the treatment and post-treatment conditions' sample, video clips were also selected randomly, but with the constraint that the independent variables' frequency must be matched to the baseline sample. For example, if a driver's baseline sample contained five video clips with windshield wiper use, the treatment and post-treatment samples would contain five video clips, respectively, with windshield wiper use.

The video clips were chosen with the following criteria:

- The minimum speed for the five-second clip duration was above 11.18 m/s (25 mph).
- The road type was either a surface street or a highway (video clips occurring on unknown or ramp road types were not included).
- No warning was given within five seconds before or after the video clip.
- Video clips were at least five minutes apart from one another.

Each selected video clip was visually coded for the presence of secondary tasks.

Results:

Table 6 displays the secondary tasks observed in the coded video clips as well as the frequency with which those tasks occurred. Multiple secondary tasks were observed in 94 video clips and each task is uniquely represented in the frequency counts in Table 6. In this analysis, eating, drinking, grooming, and smoking are broken into two categories: low involvement and high involvement. The two levels are primarily distinguished by the hand position of the driver. Tasks requiring two hands (opening food or drink packaging, securing a ponytail holder, etc.) were scored as high involvement. Tasks involving one hand were scored as low involvement (for example, a driver eating French fries with one hand and any one-handed grooming such as touching the face, head, or hair).

In 50% of the clips, the teens were not engaged in a secondary task. The most frequently occurring secondary task was talking to a passenger (22% of the clips) followed by low involvement grooming (10% of the clips). Texting, which is illegal to do while driving in Michigan, was observed in 1% of the video clips. Figure 5 provides data about participation in the most frequently occurring secondary tasks by driver group.

Table 6: Frequency of secondary tasks among the 1,279 five second video clips

Secondary Task	Number of Video Clips with Task
None	644
Dialing Phone	1
Text messaging	18
Talking on/listening to hand-held phone	43
Talking on/listening (headset or hands-free)	2
Singing/whistling	106
Talking to/listening to passenger(s)	282
Adjusting Stereo controls	30
Adjusting HVAC controls	4
Adjusting other controls on dash	4
Adjusting controls on steering wheel	2
Adjusting Navigation System	0
Adjusting other mounted aftermarket device	0
Holding device	13
Looking at device	9
Manipulating device	3
Eating: High involvement	0
Eating: Low involvement	32
Drinking: High involvement	2
Drinking: Low involvement	18
Grooming: High involvement	0
Grooming: Low involvement	128
Smoking: High involvement	0
Smoking: Low involvement	0
Reading	0
Writing	0
Searching interior	2
Reaching for object in vehicle	17
Other	13

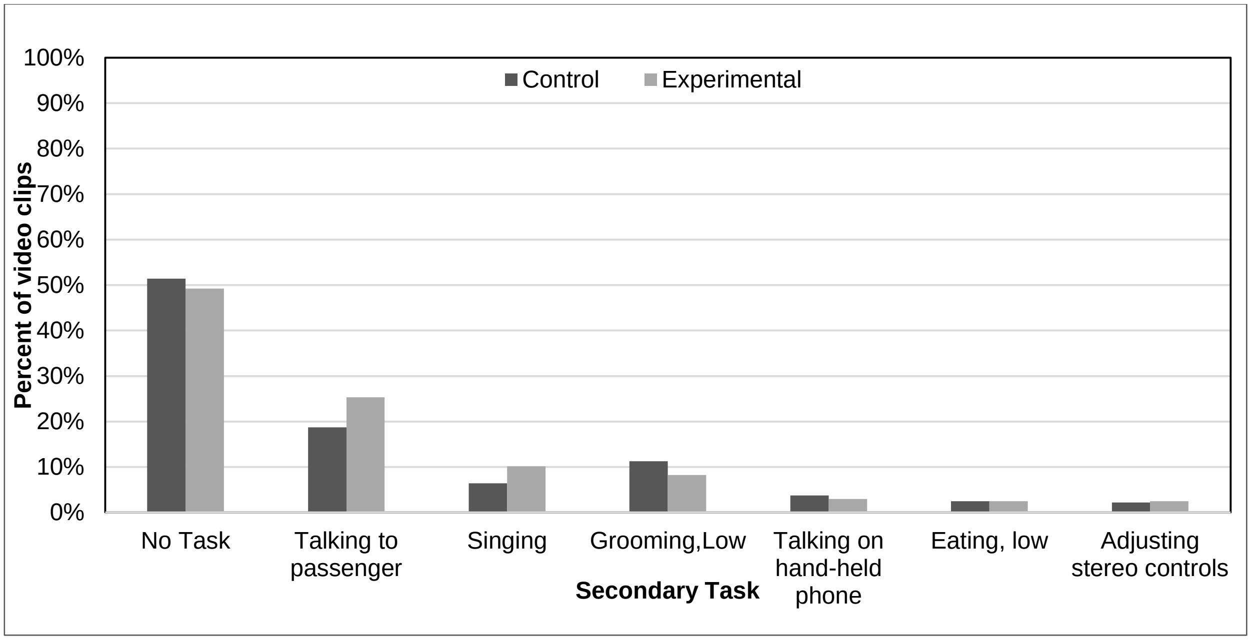


Figure 5: Percent of video clips with the most common secondary tasks by driver group

The results from the statistical analyses demonstrated a statistically significant effect of gender (X^2 (1, N = 40) = 7.03, $p < 0.01$) and road type (X^2 (1, N = 40) = 5.79, $p = 0.02$). Females were 1.3 times more likely to be involved in a secondary task while driving than their male counterparts. Additionally, drivers were 1.3 times more likely to be driving on a surface street while engaged in a secondary task than on a limited access road. There was no statistically significant effect of driver group or exposure period. Additionally, the interaction between driver group and exposure period was not statistically significant (X^2 (5, N = 40) = 4.62, p = 0.46). The means for each combination of driver group and exposure period are displayed in Table 7.

Table 7: Means for the nonsignificant interaction of driver group and exposure period for the probability of being engaged in a secondary task

Driver Group	Exposure Period	Mean
Control	Baseline	0.41
Control	Treatment	0.47
Control	Post-Treatment	0.40
Experimental	Baseline	0.46
Experimental	Treatment	0.47
Experimental	Post-Treatment	0.50

QC2: Does a driver's engagement in secondary tasks increase the frequency of crash warnings from the integrated system?

Method: For each driver, 16 video clips, 8 preceding a warning and 8 that did not precede a warning, were selected from the treatment period and analyzed for the presence of a secondary task. Generally speaking, two valid warnings of each warning type (i.e., FCW, LCM, etc.) were selected per driver. If a driver did not have any valid warnings for a particular type of warning subsystem, warnings from another type were substituted. Additionally, LDW departures were selected from those in which the driver drifted in the lane and made a correction. LDW warnings that were elicited as a result of unsignaled lane changes were not included. Only video clips that met the following criteria were included in video clip set:

- The minimum speed for the five-second duration was above 11.18 m/s (25 mph).
- The road type was either a surface street or a limited access highway
- No warning was given within five seconds before and after the video clip for the no-warn condition.
- A warning immediately followed the five-second clip for the warning condition.
- Video clips were at least five minutes apart.

Five teens, four from the control group and one from the experimental group, were excluded from the analyses because they lacked a sufficient number of valid warnings. Statistical analyses investigated the effects of the presence of a secondary task, gender, time of day, wiper state, and road type on the frequency of receiving a crash warning.

Results: The results showed statistically significant effects of secondary task involvement (X^2 (1, N = 35) = 21.1, $p < 0.01$), road type (X^2 (1, N = 35) = 12.37, $p < 0.01$), and wiper state (X^2 (1, N = 35) = 8.61, $p < 0.01$). Teens were 1.6 times more likely to receive a warning when they were not performing a secondary task, than when they were. This result may suggest that drivers are performing secondary tasks under conditions that are less demanding and less likely to produce a warning. Teens were 1.4 times more likely to receive a warning while driving on limited access roads than surface streets and 2.3 times more likely to receive a warning when the wipers were off.

QL1: Does lateral offset vary among the exposure periods?

Method: The lateral offset is defined as the distance between the center line of the vehicle and the center line of the lane as shown in Figure 6. If the vehicle is perfectly centered in the lane, lateral offset is zero.

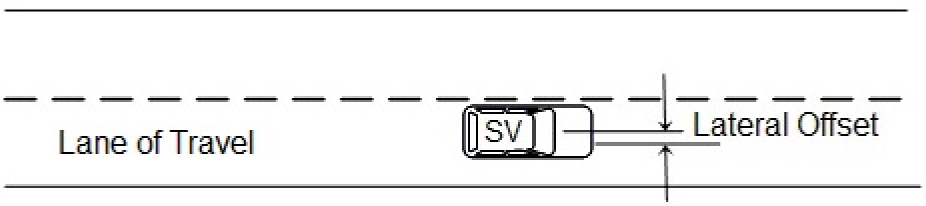


Figure 6: Conceptual drawing of lateral offset

This investigation is based on a subset of steady-state lane keeping events where the primary driving task is defined as maintaining a proper lateral offset. Intentional driving maneuvers such as lane changes and braking events were removed. When such a maneuver was performed, a buffer time of five seconds before and after was also removed to allow the driver to return to the lane-keeping task. Each lane-keeping event was required to last longer than 20 seconds to ensure that the driver settled into the driving task and eliminated short periods of driving where the driver was likely preparing for the next maneuver. Additional criteria required the lane tracking system to have known boundaries on both sides and the lane tracking status enabled to ensure that good estimates of the lateral offset were used. A list of the constraints used in this analysis can be seen in

Table 8.

Table 8: QL1 analysis constraints

Constraints
Boundary types known and real (virtual boundaries not included)
Lateral offset confidence 100 percent
Lane tracker enabled
No braking, lane changes or turn-signal use
Buffer time of 5 seconds before and after any intentional maneuver
Steady-state duration longer than 20 seconds (plus buffer)
Speed above 11.2 m/s (25 mph)

A total of 30,438 steady-state events were analyzed where the dependent variable was average lane offset and the following factors were examined: driver group, wipers, time of day, gender, exposure period, and average speed.

Results: The only statistically significant finding was that lateral offset increased as average speed increased ($F(1,39.6) = 9.36$; $p<0.01$). Negative values mean shifts to the left, while positive ones indicate lane offsets to the right of the lane. Figure 7 illustrates that for both the experimental and control groups that teens generally drove to the left of the center of the lane and this tendency increased at higher speeds. The interaction of driver group and exposure period was not statistically significant ($F(5,80.3) = 1.10$; $p = 0.37$). Means for each combination of driver group and exposure period are provided in Table 9.

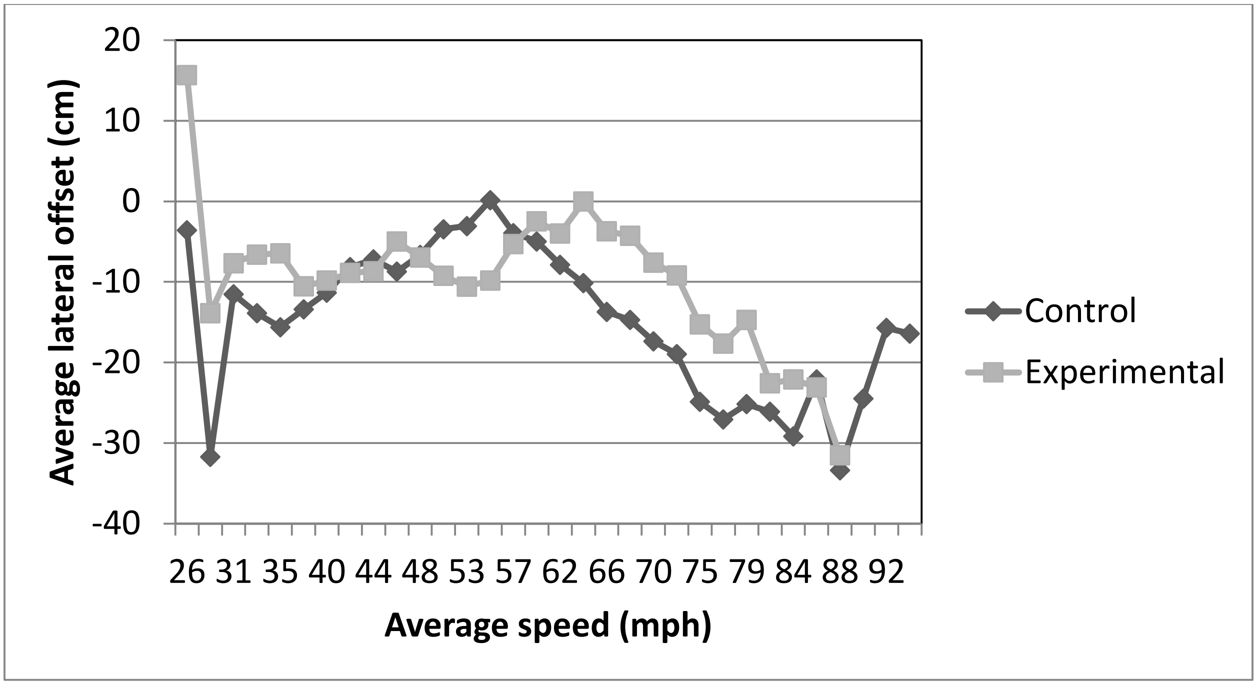


Figure 7: Average lateral offset by for each driver group versus average speed during steady-state lane keeping.

Table 9: Means for the nonsignificant interaction of driver group and exposure period for average lane offset. Negative values indicate positions to the left of the center of the lane.

Driver Group	Exposure Period	Mean (cm)
Control	Baseline	-3.8
Control	Treatment	-4.3
Control	Post-Treatment	-2.7
Experimental	Baseline	-1.5
Experimental	Treatment	-1.7
Experimental	Post-Treatment	-1.6

QL2: Does the lane departure frequency vary among the exposure periods?

Method: A total of 6,388 lane departures were analyzed. These lane departures occurred during periods of steady-state lane keeping. Active maneuvers such as changing lanes or braking were excluded. For purposes of this analysis, a lane departure is an excursion into an adjacent lane as measured by the lane tracker. The event includes both the exit from the lane and the return to the original lane. Table 10 shows the constraints on lane departures used in this analysis.

For each driver, lane departures were grouped by condition (i.e., combinations of exposure period, road type, time of day, and wiper state) and then normalized by the number of 100 miles driven in that condition to determine lane departures per 100 miles. Lane departures per 100 miles was the dependent variable. The following factors were examined: driver group, gender, wipers, time of day, exposure period, and road type.

Table 10: QL2 analysis constraints

Constraints
Outer edge of vehicle beyond the estimated lane boundary
Boundary types known and real (virtual boundaries not included)
Lateral offset confidence 100 percent
Lane tracker enabled
No braking, lane changes, or turn-signal use
Buffer time of 5 seconds before and after any intentional maneuver
Vehicle returns to lane in less than 20 seconds
Speed above 11.2 m/s (25 mph)

Results: The effect of exposure period was statistically significant ($F(2,256) = 3.77$; $p = 0.02$). The lane departure frequency was the lowest during the treatment period (Mean = 3.8 lane departures per 100 miles as compared to means of 5.0 and 5.1 lane departures per 100 miles observed in the baseline and post-treatment periods, respectively, Figure 8). The results also showed a statistically significant effect of driver group ($F(1,38.9) = 4.78$; $p = 0.03$). The lane departure rate for teens in the control group was 67% higher than the rate for teens in the treatment group (Figure 9). Time of day ($F(1,36.6) = 7.04$; $p = 0.01$) and road type ($F(1,38.6) = 16.02$; $p < 0.01$) were also statistically significant effects. Teens' lane departure frequency was higher at night, and on limited access roads as shown in Figure 10 and Figure 11. Additionally, the interaction of driver group and road type was also significant ($F(1,38.6) = 8.49$; $p < 0.01$). The interaction of driver group and exposure period was not statistically significant ($F(2,256) = 1.20$; $p = 0.30$). Means for each combination of driver group and exposure period are provided in Table 11.

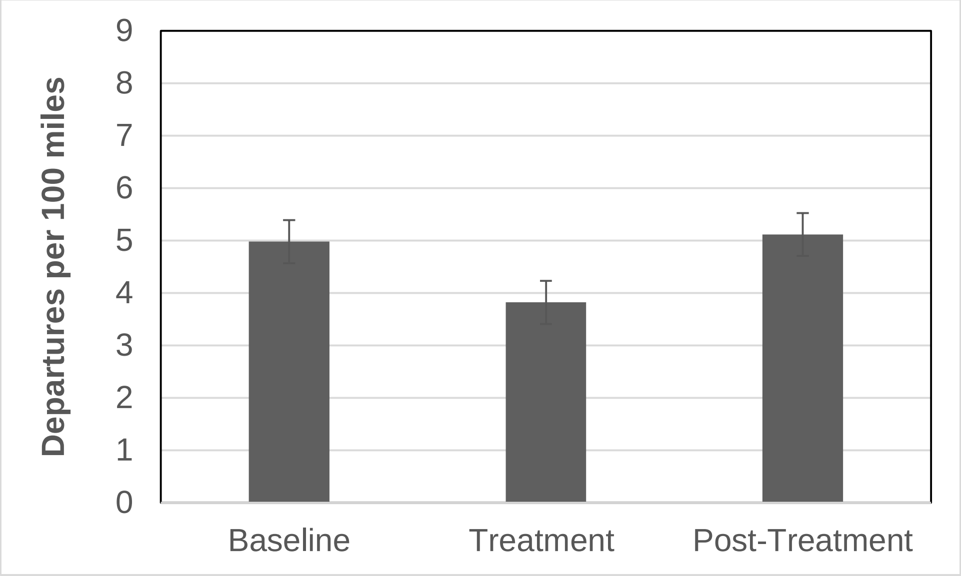


Figure 8: Mean lane departure rates for each exposure period

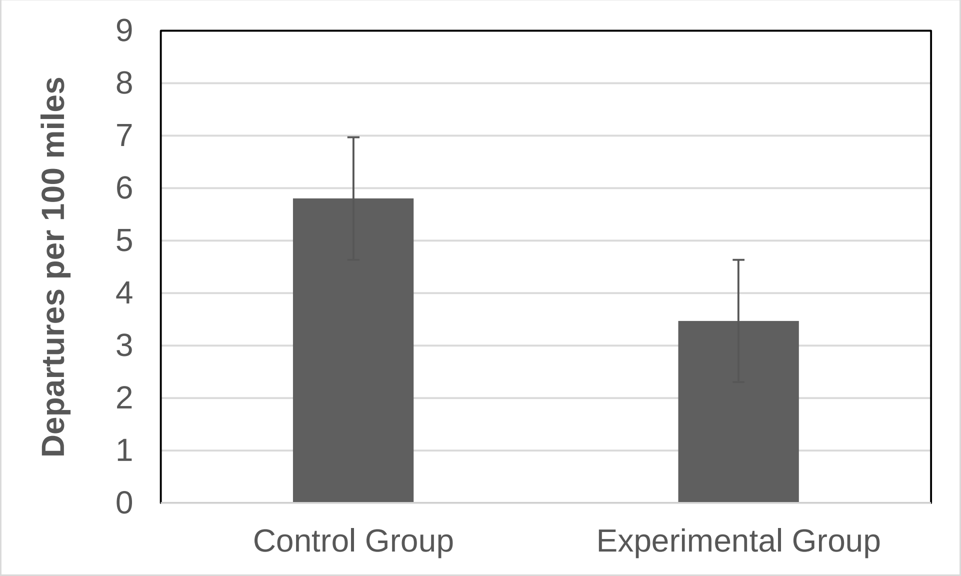


Figure 9: Mean lane departure rates by driver group

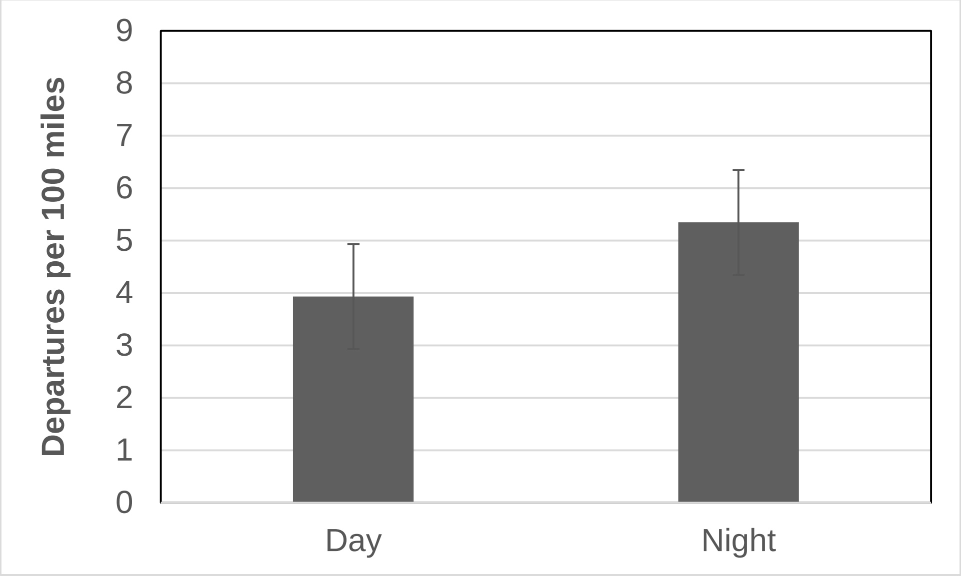


Figure 10: Mean lane departure rates by time of day

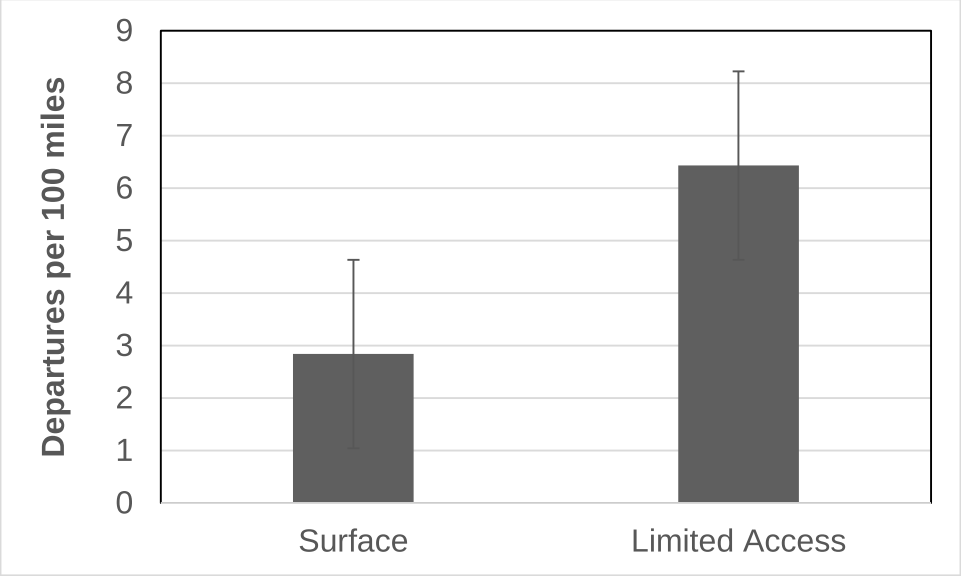


Figure 11: Mean lane departure rates by road type

Table 11: Means for the nonsignificant interaction of driver group and exposure period for lane departures per 100 miles

Driver Group	Exposure Period	Mean
Control	Baseline	6.1
Control	Treatment	5.3
Control	Post-Treatment	5.9
Experimental	Baseline	3.8
Experimental	Treatment	2.3
Experimental	Post-Treatment	4.6

QL3: When vehicles depart the lane, does the vehicle trajectory, including incursion and duration, change among the exposure periods?

Method: A total of 6,388 lane departures (the same ones from QL2) were analyzed. For each lane departure, the time from when the edge of the vehicle first crosses the lane boundary to when the entire vehicle is again in its lane was determined. In addition, the maximum lane incursion distance into the adjacent lane was recorded for each event.

All of the departure events in this analysis require the subject vehicle to return to its original lane in less than 20 seconds (see research question QL2). Table 10 in section QL2 summarizes the constraints used for this question.

The dependent measures were the time of and maximum distance of the lane incursion (Figure 12). The following factors were examined: driver group, wipers, time of day, gender, exposure period, direction of drift, and the presence/absence of an adjacent vehicle (i.e., principle other vehicle (POV), Figure 13).

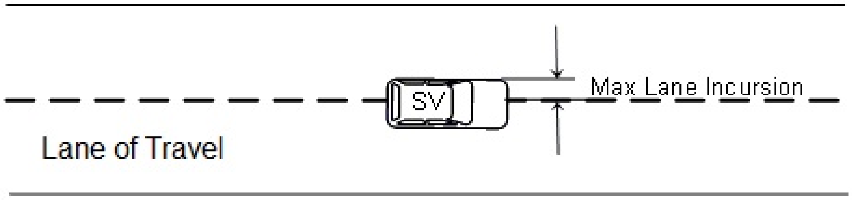


Figure 12: Illustration of lane incursion

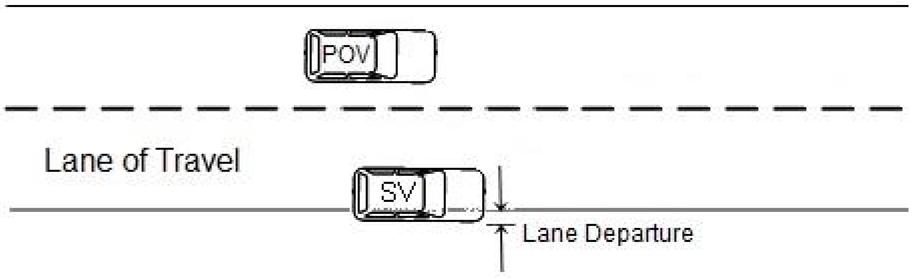


Figure 13: Illustration of lane departure with another vehicle present in the adjacent lane

Results: Statistically reliable findings for differences in departure duration were observed for driver gender (*F*(1,31.6) = 3.9; *p* = 0.05) as well as driver group (*F*(1,314) = 3.83; *p* = 0.05) Further, the presence of an adjacent vehicle, the principle other vehicle (POV), was statistically significant in terms of incursion distance (*F*(1,101) = 4.2; *p* = 0.04). Figure 14 illustrates that when male teen drivers left the travel lane, they stayed outside longer than female teens. Figure 15 illustrates that when teens in the experiment group did leave the lane of travel that they spent on average approximately 770 ms less time outside of the lane than those in the control group. Figure 16 shows that when there was an adjacent vehicle present, drivers traveled farther outside of the lane than when an adjacent vehicle was not present. The interaction of driver group and exposure period was not significant for departure duration (*F*(4,47.3) = 1.5; *p* = 0.22) nor maximum lane incursion (*F*(5, 33.1) = 0.6; *p* = 0.68). Means for each combination of driver group and exposure period are provided in Table 12 and Table 13.

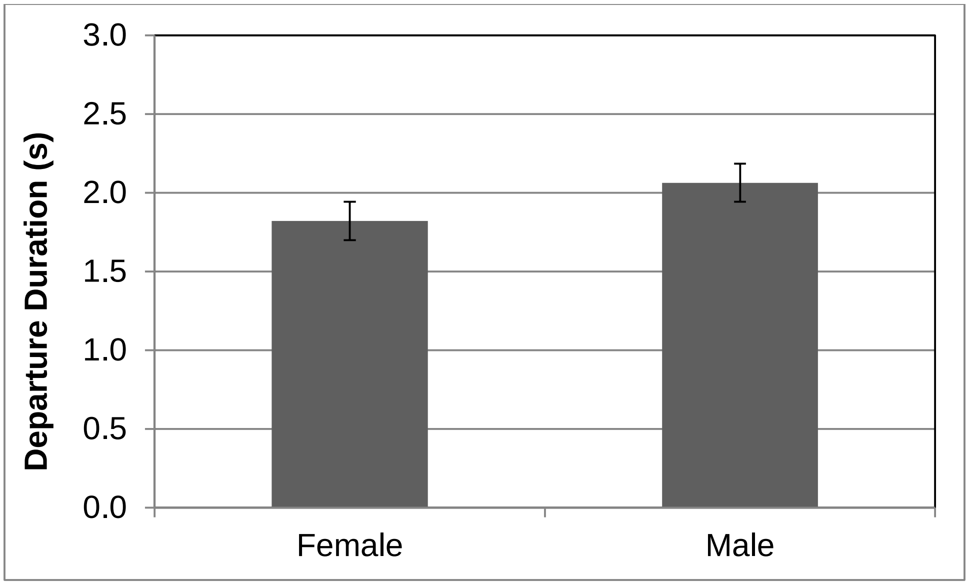


Figure 14: Mean lane incursion duration by driver gender

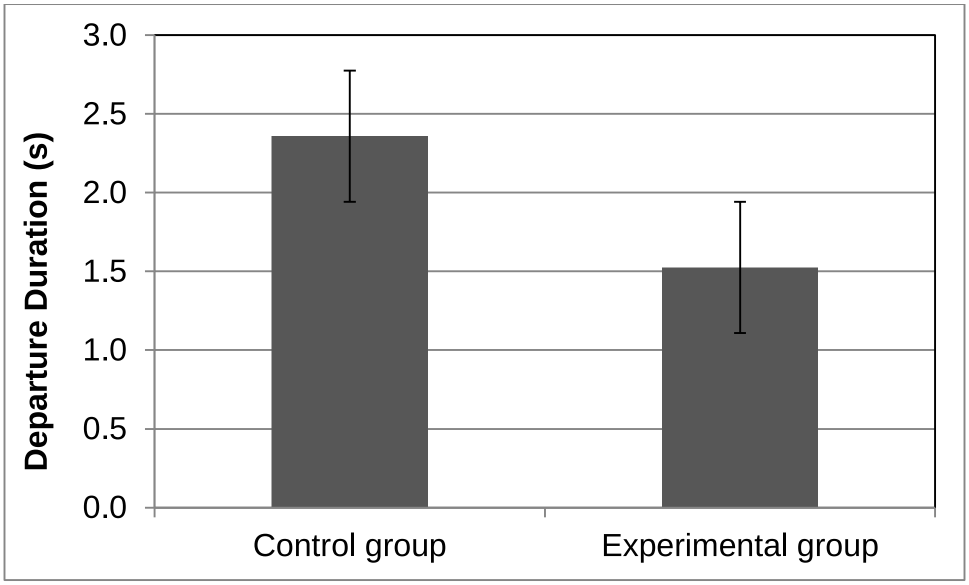


Figure 15: Mean lane incursion duration by driver group

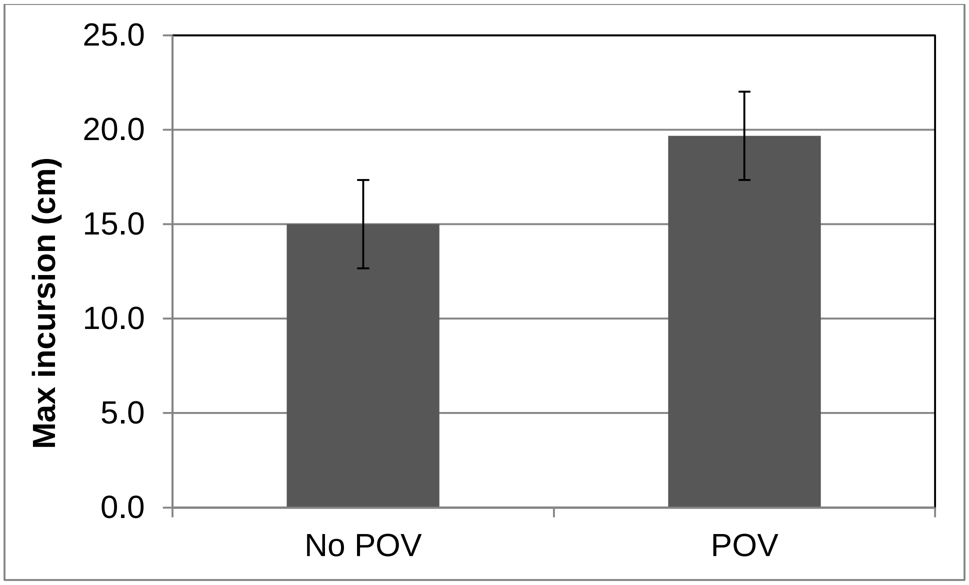


Figure 16: Maximum lane incursion distance by presence of an adjacent vehicle

Table 12: Means for the nonsignificant interaction of driver group and exposure period for lane departure duration.

Driver Group	Exposure Period	Mean (s)
Control	Baseline	2.31
Control	Treatment	2.39
Control	Post-Treatment	2.18
Experimental	Baseline	1.51
Experimental	Treatment	1.43
Experimental	Post-Treatment	1.64

Table 13: Means for the nonsignificant interaction of driver group and exposure period for maximum lane incursion distance. Negative values indicate incursions to the left.

Driver Group	Exposure Period	Mean (cm)
Control	Baseline	-17.5
Control	Treatment	-17.5
Control	Post-Treatment	-17.1
Experimental	Baseline	-17.2
Experimental	Treatment	-16.6
Experimental	Post-Treatment	-18.4

QL4: Does turn-signal use during lane changes differ among the exposure periods?

Method: A sub-set of 11,869 left and right lane-change events was used to examine turn-signal use. The analysis addressed changes in the frequency of turn-signal use during lane changes. A lane change is defined as the lateral movement of the research vehicle relative to the roadway in which the research vehicle begins in the center of a defined traffic lane with boundary demarcations, and ends in the center of an adjacent traffic lane that also has defined boundary demarcations. A lane change is defined as the instant in time when the research vehicle's centerline crosses the shared boundary between the two adjacent traffic lanes.

The statistical analysis investigated the effects of driver group, driver gender, exposure period, and road type on the percent of unsignaled lane changes.

Results: The effect of road type was statistically significant ($F(1,39.8) = 20.54$; $p < 0.01$). As Figure 17 displays, teens were twice as likely to use their turn signals on limited access roads as compared to surface streets. The interaction of driver group and exposure period was also statistically significant ($F(5,82.4) = 3.39$; $p = 0.01$). While Figure 18 displays all of the pairwise combinations of driver group and exposure periods, not all of the pairwise comparisons revealed significant differences. The percentage of unsignaled lane changes executed by the control group during the treatment period was nearly double that of their rate during the baseline period (15% and 8%, respectively). This difference was statistically significant. During the treatment period, the percentage of unsignaled lane changes of the control group was statistically different than that of the experimental group (15% versus 3%). Finally pairwise comparisons revealed statistical differences between the percentages of unsignaled lane changes observed in the post-treatment period behavior of the control group compared to each exposure period for the experimental group.

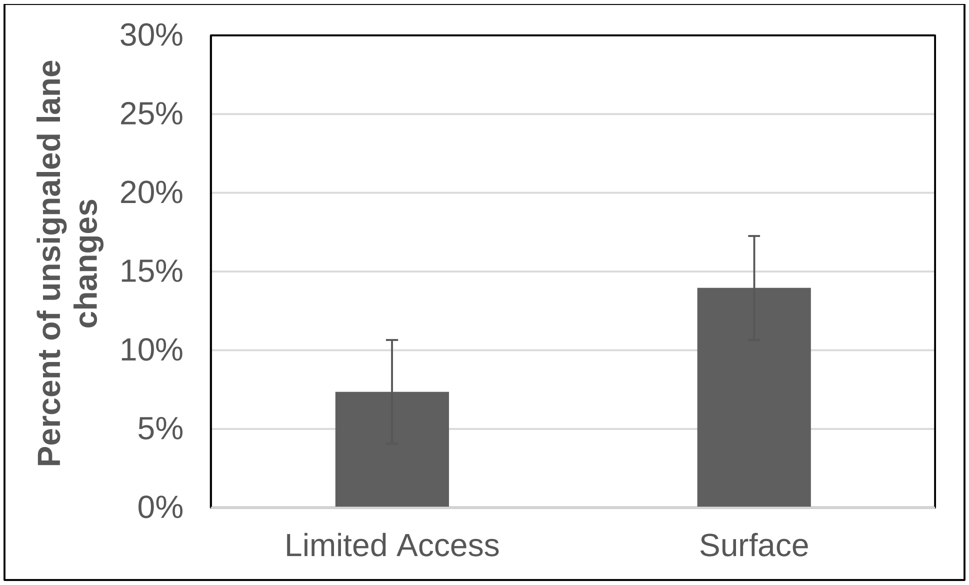


Figure 17: Percent of unsignaled lane changes by road type

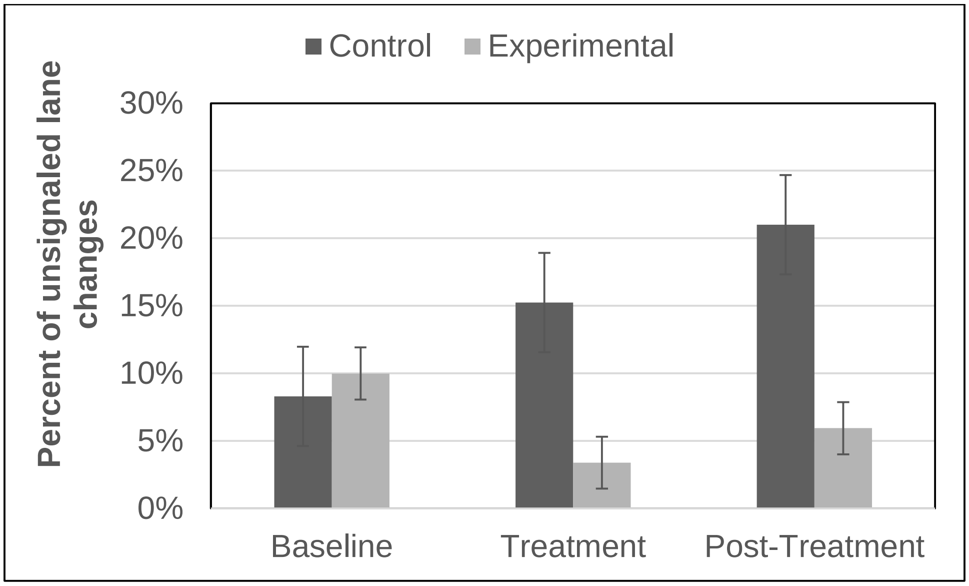


Figure 18: Percent of unsignaled lane changes for each driver group by exposure period

QL7: Will drivers change lanes less frequently in the treatment period, once the integrated system is enabled?

Method: This research question examined 4,115 lane changes to determine if the frequency of lane changes varied by exposure period. For the purpose of this report, a lane-change is defined as the lateral movement of the research vehicle relative to the roadway in which the research vehicle starts in the center of a defined traffic lane with boundary demarcations and ends in the center of an adjacent traffic lane that also has defined boundary demarcations. The explicit instant in time of the lane-change is defined as the moment when the research vehicle's lateral centerline crosses the shared boundary between the two adjacent traffic lanes.

The set of lane changes used in this analysis was constrained using the rules stated in Table 14. These constraints ensure that the set of lane changes analyzed does not contain events that were not intended to be lane changes by the driver. For example, a driver may intentionally occupy part of an adjacent traffic lane while maneuvering away from a stationary vehicle on the shoulder, or may inadvertently drift laterally into an adjacent lane before returning to the center of the original lane, especially at night and in low traffic situations.

Table 14: QL7 analysis constraints

Constraints
Boundary types known and lateral offset confidence 100%
Lane change is across a dashed boundary type
Lane change is performed on a straight segment of roadway
Turn signal active for at least 1 second before the lane change
Speed above 11.2 m/s (25 mph)
No intentional lateral maneuvers in a 5-second window prior to the lane-change (i.e., the equipped vehicle is in a steady-state condition within its lane)

Results: The results of the mixed model showed that teens changed lanes on limited access roads nearly five times as often as they did on surface streets ($F(1,40.9) = 58.34$; $p < 0.01$). There was also a statistically significant increase in the rate of lane changes associated with driving during the day (28% increase, ($F(1,624) = 8.36$; $p < 0.01$). These results are presented in Figure 19 and Figure 20. The interaction of driver group and exposure period was not statistically significant ($F(5,298) = 0.28$; $p = 0.92$). Means for each combination of driver group and exposure period are provided in Table 15.

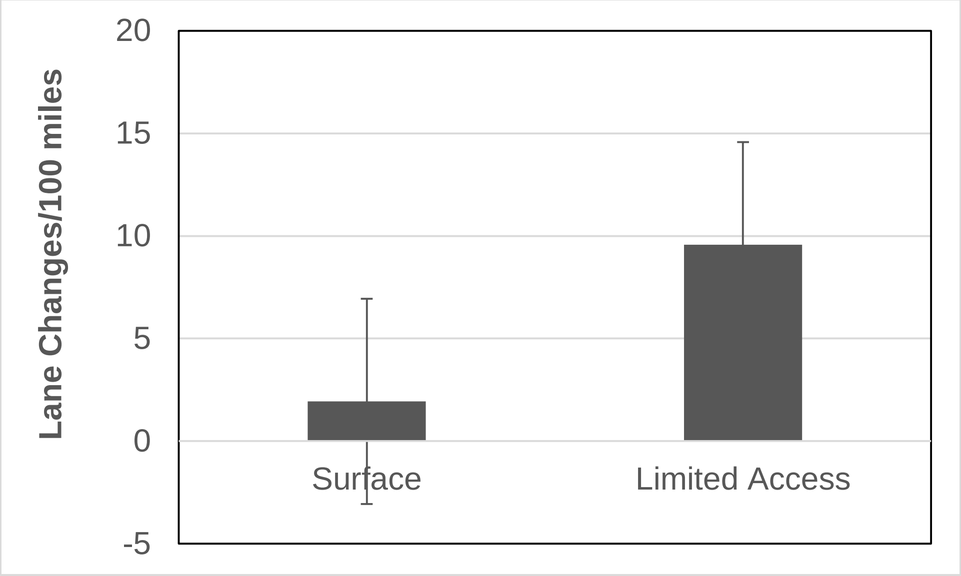


Figure 19: Mean lane change rates by road type

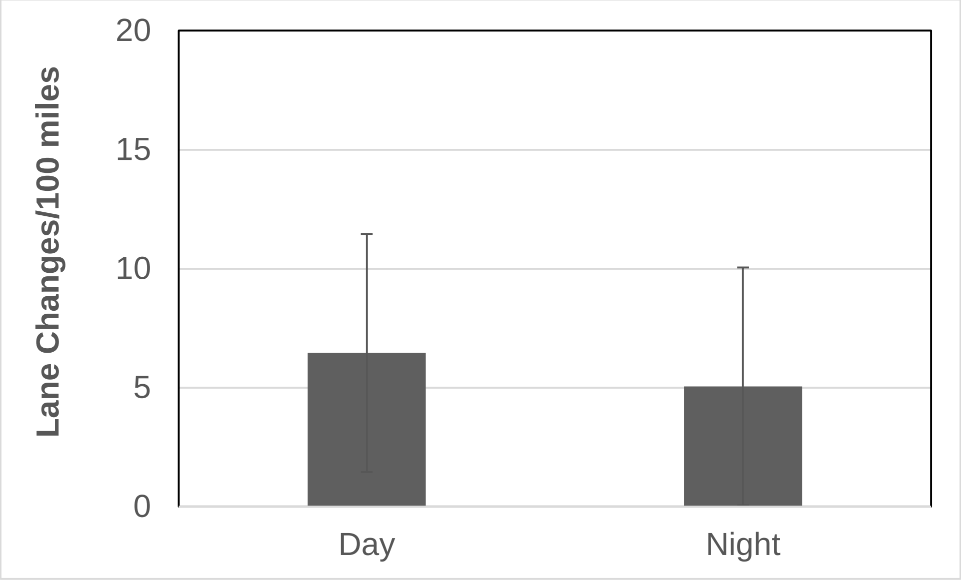


Figure 20: Mean lane change rates by time of day

Table 15: Means for the nonsignificant interaction of driver group and exposure period for lane change rates.

Driver Group	Exposure Period	Lane changes/100 miles
Control	Baseline	6.2
Control	Treatment	6.4
Control	Post-Treatment	6.6
Experimental	Baseline	5.2
Experimental	Treatment	5.1
Experimental	Post-Treatment	5.0

QF1: Does the presence of the integrated system affect the following distance for teen drivers?

> **Method:** This analysis addresses periods of steady-state following (see Figure 21) and evaluated whether the fraction of following time spent at short headways is affected by the integrated system. The same definition of steady-state following used in the IVBSS FOT study was applied for this analysis and its constraints are provided in Table 16.

Table 16: QF1 steady-state following constraints

Constraints
Presence of a lead vehicle
Speeds between 11.2 and 35.8m/s (25 to 80 mph)
Traveling with a time headway of less than 3.5 seconds
Following with a relative closing speed between -2.2 and +2.2m/s (-5 to +5mph)

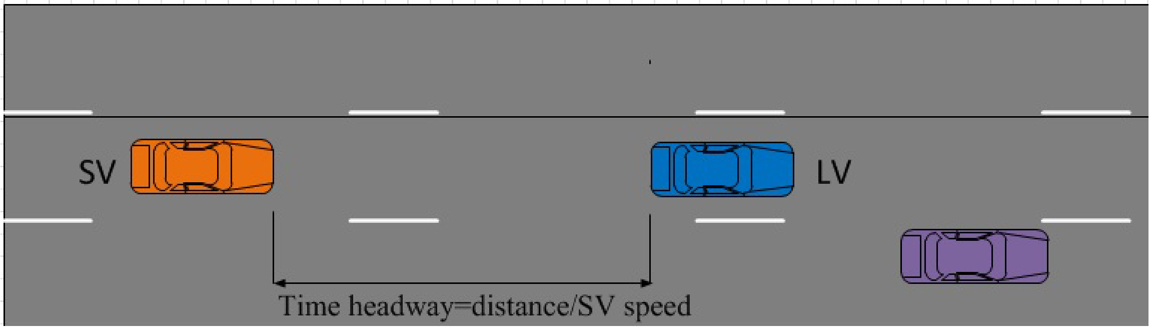


Figure 21: Steady-state following

The dependent variable for this analysis is the percentage of steady-state following time where the headway time is less than one second. This value was selected since analyses showed that it was this range of short headways that were most affected by a forward-crash warning system

(Ervin et al., 2005). Also, headway time of less than one second are usually considered to be following too closely for safety.

A mixed model analysis was used. The data are 10 Hz samples of headway time within periods of steady-state following. A total of 70,317 steady following events were observed and used in the analysis. The analyses were performed with linear mixed models using the PROC MIXED procedure in the statistical software package SAS 9.2. Fixed effect predictors included driver group, road type, traffic density, wiper, day/night, exposure periods, and gender. Driver and interactions between driver and any fixed effects were treated as random effects. This accounts for within-subject variance from repeated observations from the same driver and effectively compares a driver to him/herself. All the models were built in a stepwise manner by entering the entire candidate variables and removing the non-significant ones.

Results: The 70,317 steady-state following events included each of the 40 FOT drivers, both for steady-state time and headway times of less than one second. The impact of driver group variable was not found significant. However, it was included in the final model because it was of the project's primary interests to see if there were differences between the control and experimental group teens.

Results of the final model showed that only exposure period variable showed significant effects ($F(2,75.9) = 9.61$, $p<0.01$). As shown in Figure 22, teens spent significantly more time following within 1 second headway during the treatment (mean = 25%) and post treatment periods (mean = 25%) than the baseline period (mean = 20%). No significant differences were found between the treatment and post treatment periods. Teens in the control group had a higher proportion of time in a short headway zone than teens in the treatment group (26% vs. 21%), but not at a statistically significant level.

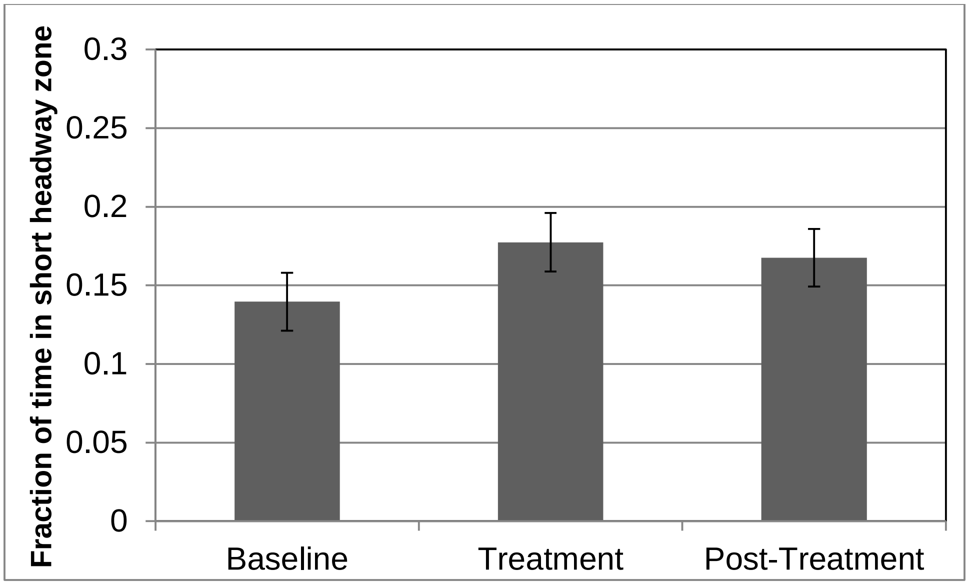


Figure 22**:** Fraction of time in short headway zone under three exposure periods with standard error bars

Other main effects of road type *F*(1,37.8) = 235.6, $p < 0.01$ and traffic *F*(2,55.3) = 22.34, $p < 0.01$ were also significant. Figure 23 shows that teens spent nearly three times as much time driving in a short headway zone on limited access roads as compared to surface streets. Additionally, not surprisingly, teens spent the highest percentage of time driving at short headways in dense traffic as compared to moderate and sparse traffic (26%, 24%, and 20% respectively, Figure 24). The interaction effect between driver group and exposure period is not significant ($p>0.05$). Table 17 presents the mean fraction time in short headways for each driver group during each exposure period.

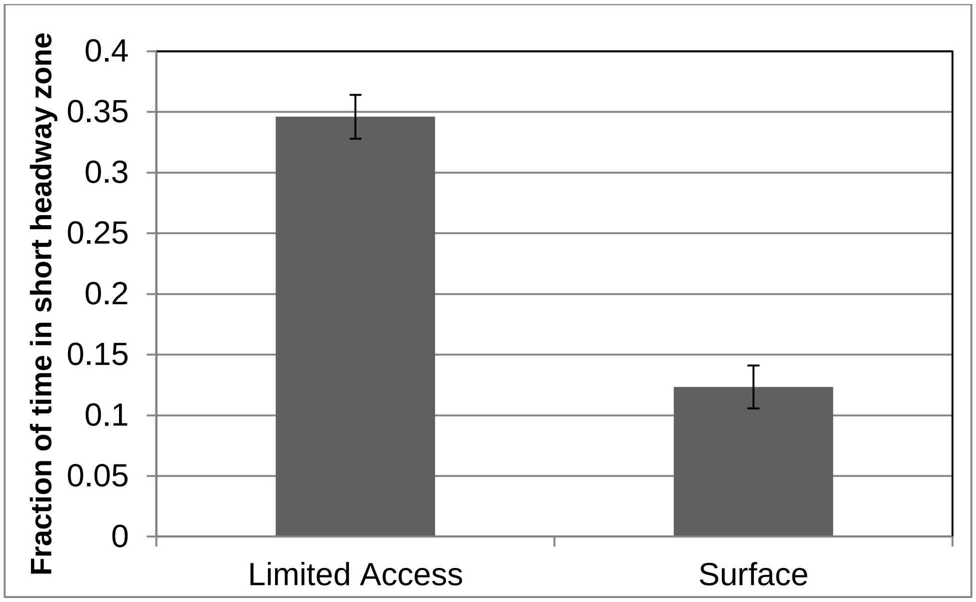


Figure 23: Fraction of time in short headway zone by road type with standard error bars

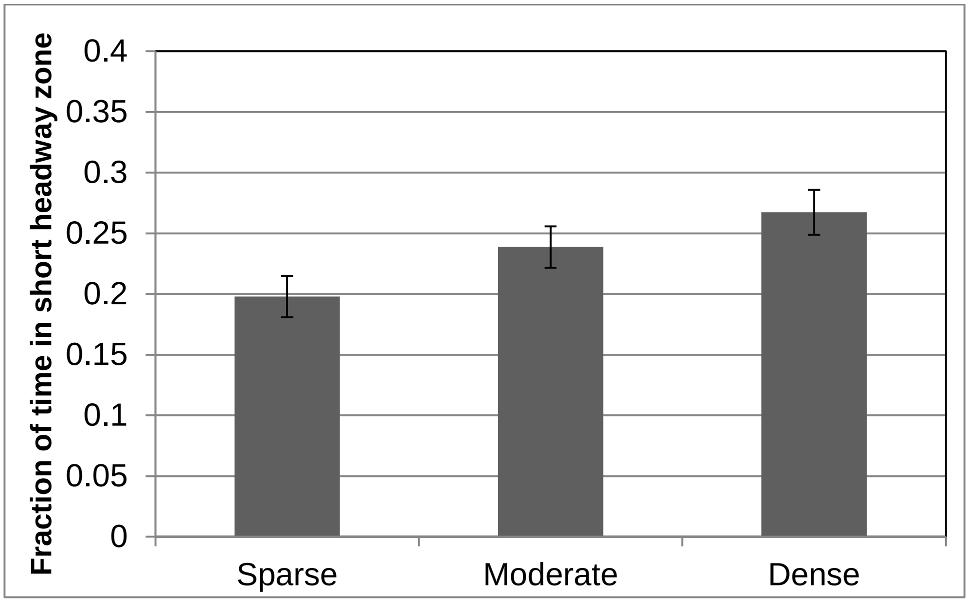


Figure 24: Fraction of time in short headway zone by traffic density with standard error bars

Table 17: Means for the fraction of time in short headway zone by driver group and exposure period (non-significant effect)

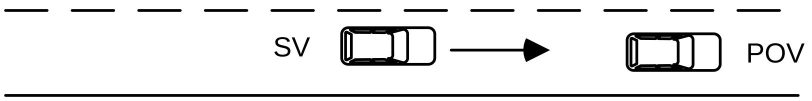
Driver Group	Exposure Period	Mean
Control	Baseline	0.24
Control	Treatment	0.27
Control	Post-Treatment	0.28
Experimental	Baseline	0.17
Experimental	Treatment	0.22
Experimental	Post-Treatment	0.23

QF2: Will the magnitude of forward conflicts be reduced between baseline, treatment and post-treatment conditions?

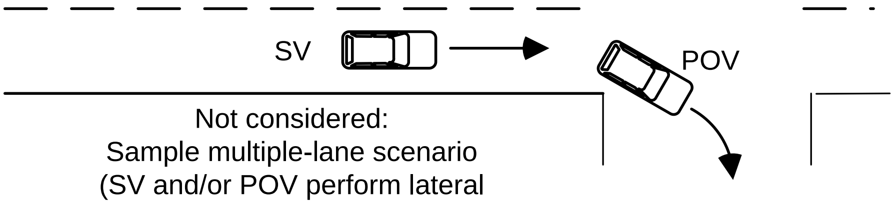
Method: This analysis addressed forward conflicts with a lead vehicle in 14,900 events. The measure of forward conflict is the minimum level of required deceleration to avoid a collision with the forward vehicle during the event. The definition of the required deceleration used is the same as that in the adult IVBSS study, the constant level of braking needed to simultaneously bring range and closing speed to zero, i.e., to just avoid impact. Required deceleration is negative when braking is needed, so that the minimum value is the greatest magnitude of braking required. Table 18 displays the criteria used to select forward conflicts.

Table 18: QF2 following constraints

Constraints
Time-to-collision (the range to the lead vehicle divided by the following vehicle's closing speed) falls below 10 seconds and the required deceleration is less than +0.5 m/s^2 or the required deceleration falls below -1 m/s^2
Speed is between 11.2 and 35.8 m/s (25 and 80 mph)
Conflicts with objects that the radar never observed to be moving were discarded because of the difficulty of identifying which were legitimate rear-end threats
Only valid trip conflicts were considered
Conflicts that occurred when the roadway type was not known were discarded
Only those conflicts that met the minimum level of conflict, as described above, were used
Only conflicts that were shared-lane scenarios were used



Considered: Shared-lane scenario
(SV and POV in same lane throughout scenario)



Not considered:
Sample multiple-lane scenario
(SV and/or POV perform lateral
maneuver during the conflict episode)

Figure 25: Definition of a closing conflict event

These conditions were used because the resulting events were ones in which the driver typically slows the vehicle, whether through braking or releasing the throttle. Many subsequent processing steps are needed to ensure that each event is truly a unique encounter with a lead vehicle. Thus, the radar data is filtered to identify and bridge signal dropouts, target index changes, and to recognize when a radar target shift is still associated with the same lead vehicle. Mixed model analysis was used. Driver group, gender, road type, wiper state, traffic, exposure period and time of day were all factors examined by the model.

Results: Statistically significant differences were observed among different exposure periods ($F(2,55.6) = 4.32$, $p < 0.01$). The mean of the required deceleration for the conflict set was -0.79, -0.77 and-0.76 m/s^2 in the baseline, treatment, and post-treatment periods, respectively. Teen drivers had higher forward conflict levels under the baseline condition than both the treatment and post-treatment conditions (Figure 26). The results also showed significant effects of traffic ($F(2,594) = 5.83$, $p < 0.01$) and road type ($F(1,70.4) = 42.7$, $p < 0.01$). Teens had lower forward conflict levels under moderate traffic volumes as compared to sparse and dense levels of traffic (Figure 27). The mean required deceleration levels to avoid a conflict were higher on surface streets than limited access roads (-0.87 m/s^2 and -0.68 m/s^2 respectively, Figure 28).

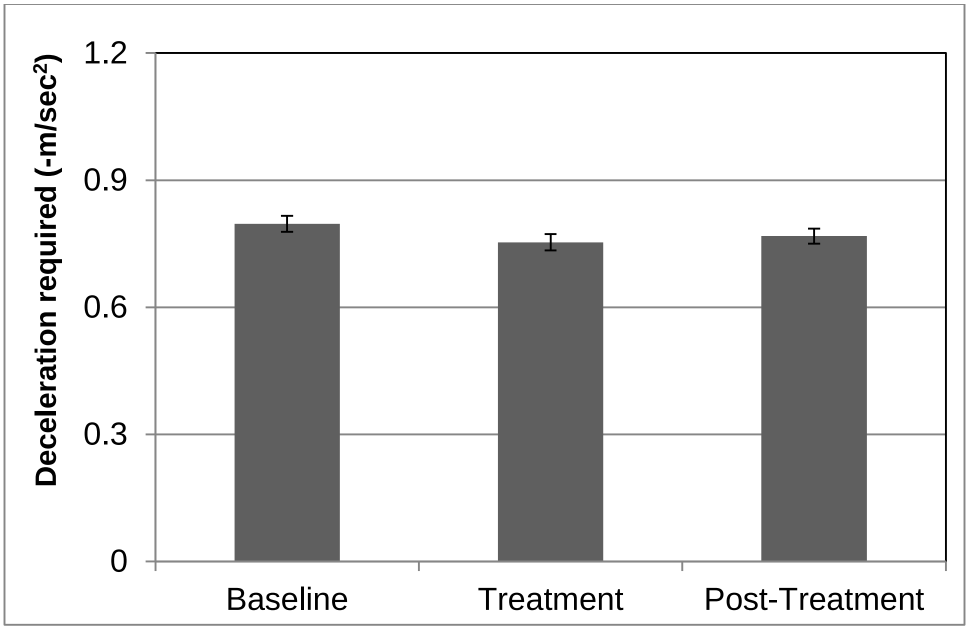


Figure 26: Required deceleration level by exposure period with standard error bars

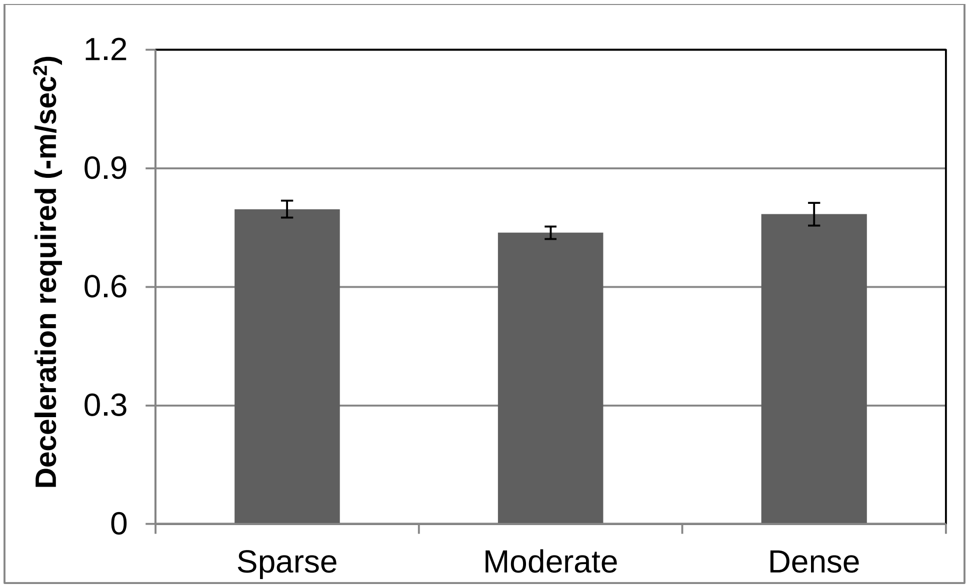


Figure 27: Required deceleration level by traffic density with standard error bars

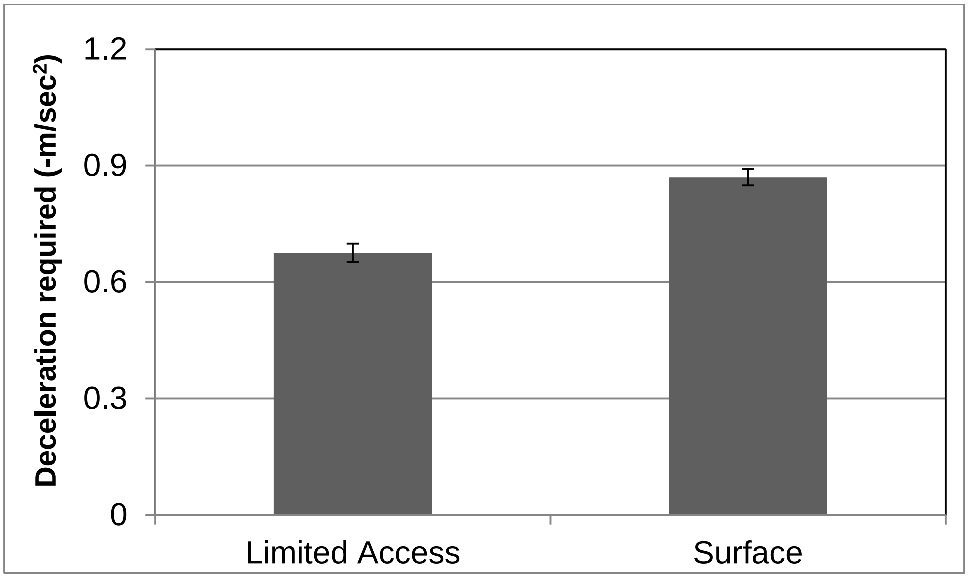


Figure 28: Required deceleration level by road type with standard error bars

The interaction of roadway type and traffic density level was statistically significant (*F*(2,596) = 6.16, $p < 0.01$). Generally, teen drivers had higher forward conflict levels when driving on surface roads when compared to driving on limited-access highways. Teen drivers also drove more aggressively under sparse traffic conditions (i.e., higher deceleration level required). The interaction effect between driver group and exposure period was not significant and the means was shown in Table 19.

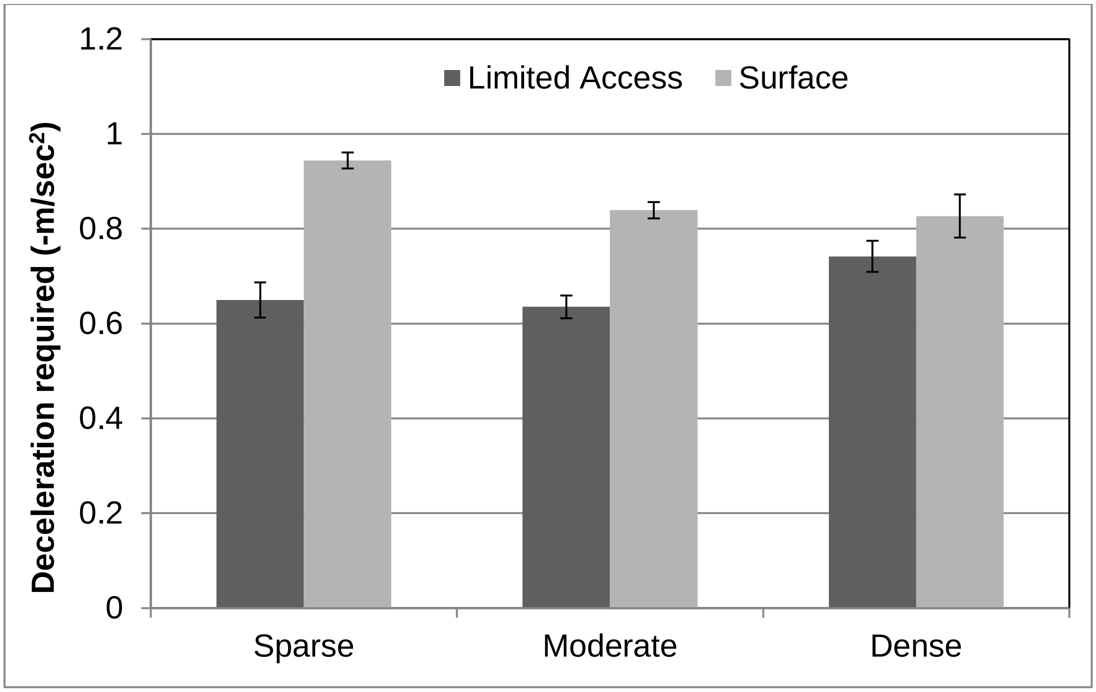


Figure 29**:** Required deceleration level by road type and traffic density with standard error bars

Table 19: Mmeans for the deceleration required by driver group and exposure period (non-significant effect)

Driver Group	**Exposure Period**	**Mean (-m/s^2)**
Control	Baseline	0.78
Control	Treatment	0.77
Control	Post-Treatment	0.74
Experimental	Baseline	0.81
Experimental	Treatment	0.77
Experimental	Post-Treatment	0.77

QF3: Will the frequency of hard braking maneuvers be reduced between baseline, treatment and post-treatment conditions?

Method: The actual braking level is an important parameter in driving safety assessment. The consideration of actual braking levels recognizes that hard braking, whether required or not, may contribute to crash risk. Only those events in which a POV contributed to the driver's use of the brake are considered in this analysis. For instance, the analysis does not address cases in which the equipped vehicle is stopping without a lead POV present. The dependent variable is the frequency of hard braking events. The data selected for analysis was constrained by the conditions listed in Table 20 below:

Table 20: QF3 analysis constraints

Constraints
Maximum speed above 11.2 m/s (25 mph) during the braking events
Presence of a lead vehicle
Peak braking level is at least 0.45g

Results: A total of 1,492 hard braking events were identified and used in this analysis. Only road type showed significant effects (F(1,11.9) = 43.92, $p < 0.05$) .The frequency of hard braking events was higher on surface streets than on limited access roads (least square means = 17.6/100 miles on surface roads; least square means = 9.8/100 miles on highways, Figure 30). No significant interaction effects were observed. Table 21 shows the mean hard braking event rates for each driver group during each exposure period.

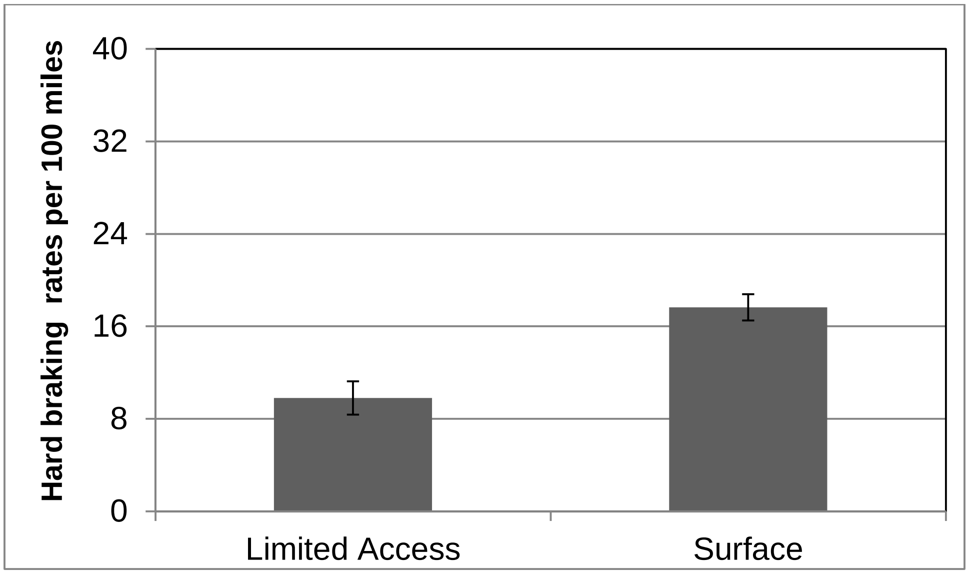


Figure 30**:** Hard braking frequency by road type. Standard error bars are shown.

Table 21: Means for hard braking events rate by driver group and exposure period (non-significant effect)

Driver Group	Exposure Period	Mean (per 100 miles)
Control	Baseline	10.87
Control	Treatment	15.29
Control	Post-Treatment	11.28
Experimental	Baseline	13.80
Experimental	Treatment	15.07
Experimental	Post-Treatment	16.05

QF4: Will the safety system improve drivers' reaction to forward conflicts?

Method: For this analysis, data from the closing conflict events (i.e. with issued FCW warnings) were examined. The dependent measure was drivers' braking reaction time—the time duration (in seconds) between the warning onset and the time when the driver initiated braking. Mixed model analysis was used. The analyses were performed with linear mixed models using the PROC MIXED procedure in the statistical software package SAS 9.2. Fixed effect predictors included driver group, road type, traffic density, wiper, day/night, exposure periods, and gender. Driver and interactions between driver and any fixed effects were treated as random effects. This accounts for within-subject variance from repeated observations from the same driver and effectively compares a driver to him/herself. The data selected for analysis was constrained by the conditions listed in Table 22.

Table 22: QF4 analysis constraints

Constraints
Speed above 11.2 m/s (25 mph)
Presence of a lead vehicle
A closing conflict
Driver's response time within 3 seconds (to consider only responses to the current conflict)
Driving on a limited access highway or surface street

Results: A total of 80 closing-conflict FCW events with brake reaction met the above constraints and were used in the following analyses. No significant main effects nor interaction effects were found. Control group drivers responded to the forward conflicts slower (mean = 0.61 s) than drivers from experimental group (mean = 0.52 s), but the difference is not statistically significant. The interaction effect between driver group and exposure period was not significant and Table 23 shows the mean brake reaction time for each driver group during each exposure period.

Table 23: Teen means of the brake reaction time by driver group and exposure period (non-significant effect)

Driver Group	Exposure Period	Mean (in seconds)
Control	Baseline	0.78
Control	Treatment	0.60
Control	Post-Treatment	0.45
Experimental	Baseline	0.72
Experimental	Treatment	0.44
Experimental	Post-Treatment	0.41

QF5: Does the rate of FCWs per 100 miles received by the treatment and control groups vary among the exposure periods?

For this analysis, FCW warning rate per 100 miles were compared between the two driver groups. Driver group, gender, road type, wiper state, exposure period, and time of day were all factors examined in a mixed model.

Results: In the final model all non-significant variables were removed, except the interaction between driver group and experimental period (in order to test the effect of the safety system). Results showed that experimental period had a significant impact on the FCW rates ($F(2,72) = 4.90$, $p < 0.05$). As Figure 31 displays, the FCW rate during the baseline period (mean = 0.24/100 miles) was significantly less than during both the treatment (mean = 0.43/100 miles) and post-treatment (mean = 0.52/100 miles) periods. No significant differences were observed between the treatment and post-treatment periods.

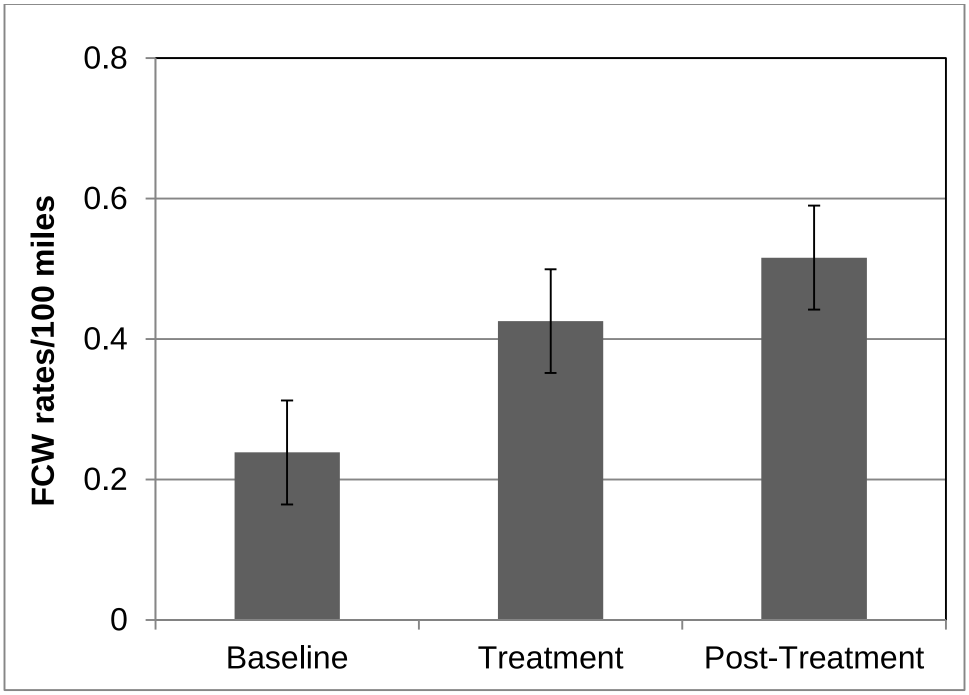


Figure 31: FCW rates by exposure period with standard error bars

The interaction between control group and gender also showed significant effects (*F*(1, 34) = 9.08, $p < 0.01$). In the control group, males had a significantly higher FCW warning rate than female drivers while the opposite trend was found in the experimental group (Figure 32). The interaction between the driver group and exposure period was not significant suggesting there is no significant system effect and mean FCW rates for each driver group is summarized in Table 24.

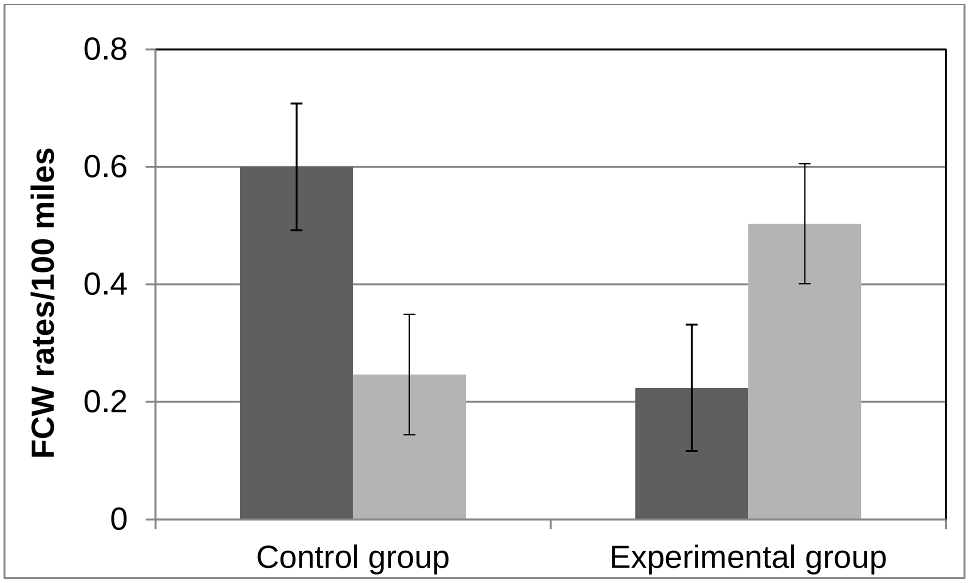


Figure 32: Teen interaction of gender and driver group on FCW rates per 100 miles. Standard error bars are shown.

Table 24: Means of the FCW rates by driver group and exposure period (non-significant effect)

Driver Group	Exposure Period	Mean (per 100 miles)
Control	Baseline	0.28
Control	Treatment	0.46
Control	Post-Treatment	0.53
Experimental	Baseline	0.20
Experimental	Treatment	0.39
Experimental	Post-Treatment	0.50

Driver Acceptance Research Questions

This section discusses key findings on driver acceptance of the overall integrated system. Results are predominantly based on results from the post-drive survey regarding the integrated crash warning system overall. The majority of the questions employed a 7-point rating scale. Higher numbers correspond to positive attributes. Additionally, there were some open-ended questions. Finally, five of the questions made use of the van der Laan scale (Van Der Laan, Heino, and DeWaard, 1997). The van der Laan scale represents one way to broadly capture drivers' subjective assessments of usefulness and satisfaction with a new automotive technology. The van der Laan Scale of Acceptance uses a five-point scale to assess nine different attributes of a given technology. Each item on the van der Laan scale is anchored by two polar adjectives, such as "good" and "bad", and the driver is asked to rate their perception of the technology by marking a box along a continuum between these two poles. Each participant assessed the system for nine pairs of adjectives, and the responses were then grouped into two categories, "usefulness" and "satisfaction." Scale scores range from -2 to +2, with positive numbers indicating positive feelings about a technology. For each question, overall means and standard deviations as well as means and standard deviation for each age group are presented in Appendix A.

QC4: Do drivers report changes in their driving behavior as a result of the integrated crash warning system?

Results: When teens were asked if their driving behavior changed as a result of the integrated system, 60% replied that it had. Drifting less often, checking and then maintaining proper lane position, and driving more cautiously were each reported by 10% of the teens. One teen reported that he was more relaxed while driving and became less aware, a negative, unintended consequence of driving with the integrated system. When asked if they relied on the integrated system, 85% of the teens responded that they had not. Two-thirds of the teens who reported relying on the system stated that they relied on the blind spot detection system.

QC5: Are drivers accepting of the integrated system?

Results: Overall, the teens were accepting of the integrated system. Van der Laan scores were calculated to investigate how useful drivers perceived the system to be and how satisfied they were with the integrated system. The mean usefulness score was 1.1 while the mean satisfaction score was 0.4. Both scores indicate positive feelings about the crash warning system. Teens also rated each subsystem and the results showed the following:

- The blind spot detection system was rated the highest in terms of both usefulness and satisfaction
- Both LDW and LCM were rated similarly to the overall system in terms of satisfaction and usefulness
- While teens were generally dissatisfied with the FCW subsystem, they were positive about its usefulness.

Overall, teens were satisfied with the integrated system (Mean = 5.0, Figure 33). Further, when asked if they would like to have the integrated system in their personal vehicle, more than half of the teens responded that they “probably would” or “definitely would” (Figure 34).

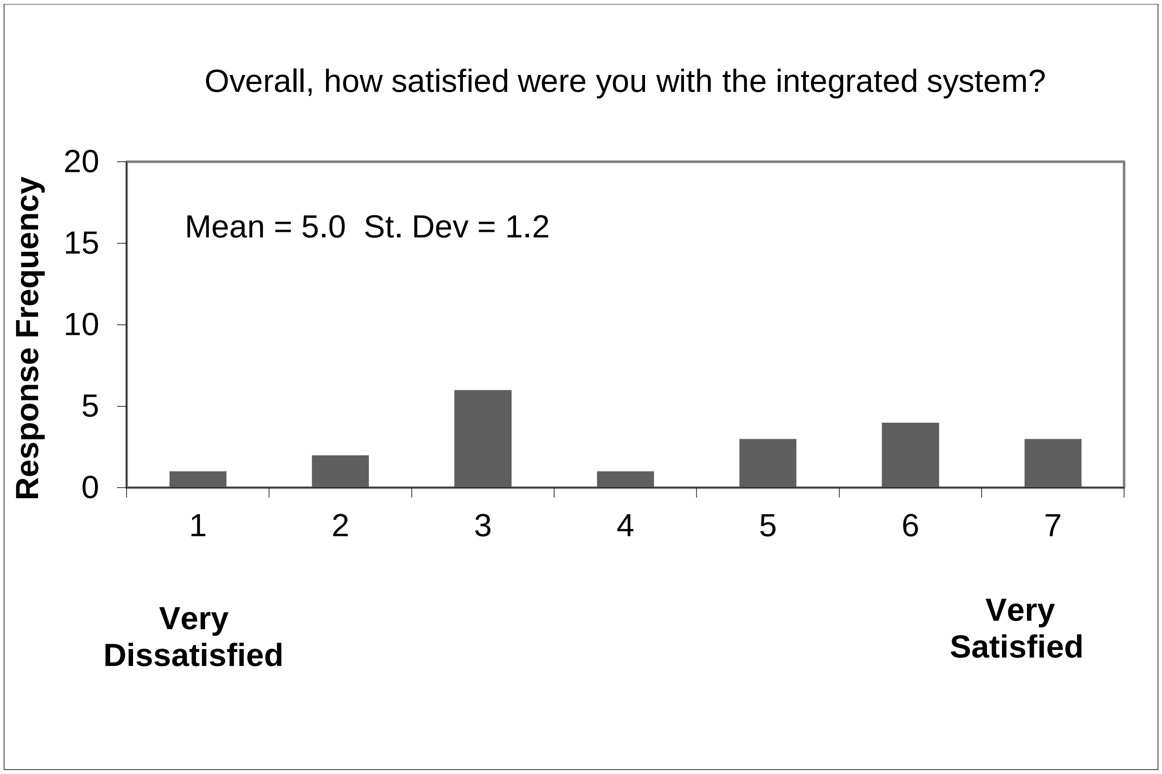


Figure 33: Ratings of satisfaction with the integrated system

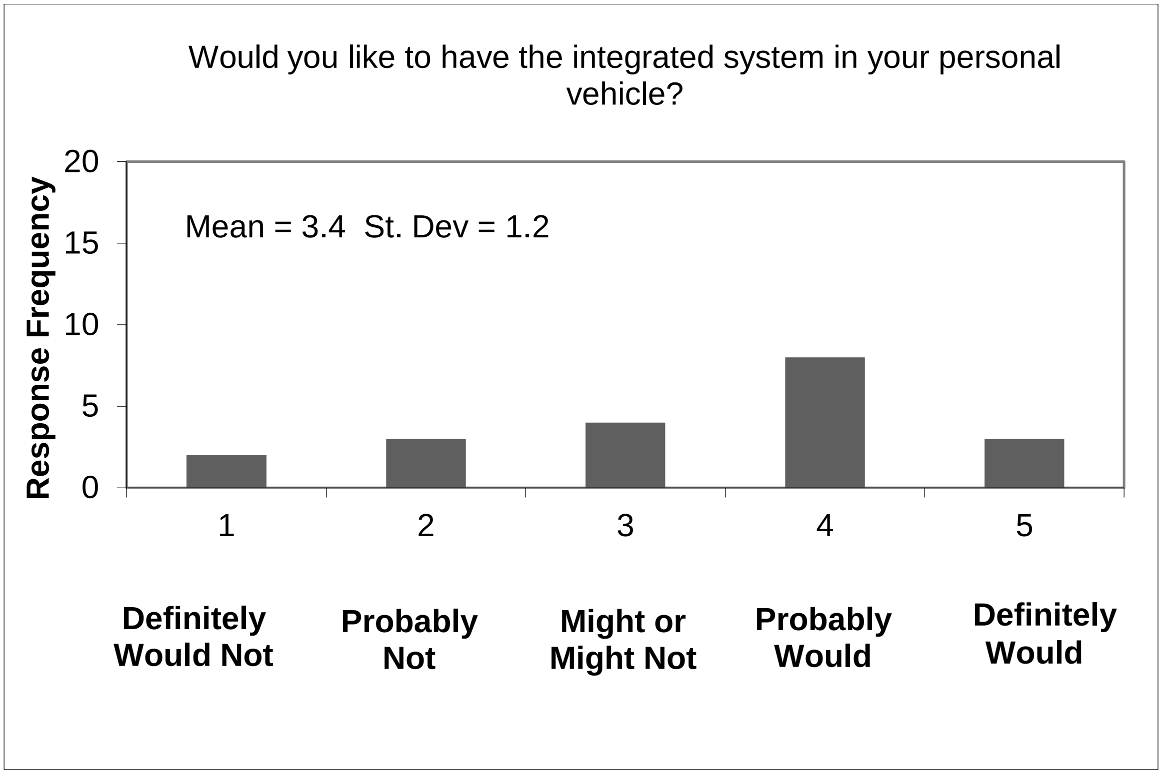


Figure 34: Willingness to have the integrated system in their personal vehicle

QC7: Do drivers perceive a safety benefit from the integrated system?

Results: Overall, teens in the treatment group perceived a safety benefit from the integrated system. In the post-drive questionnaire, they reported that they believed that the integrated system was going to increase their driving safety (Mean = 4.8) and found the warnings to be helpful (Mean = 4.9) particularly when changing lanes. These results are displayed in Figure 35 and Figure 36.

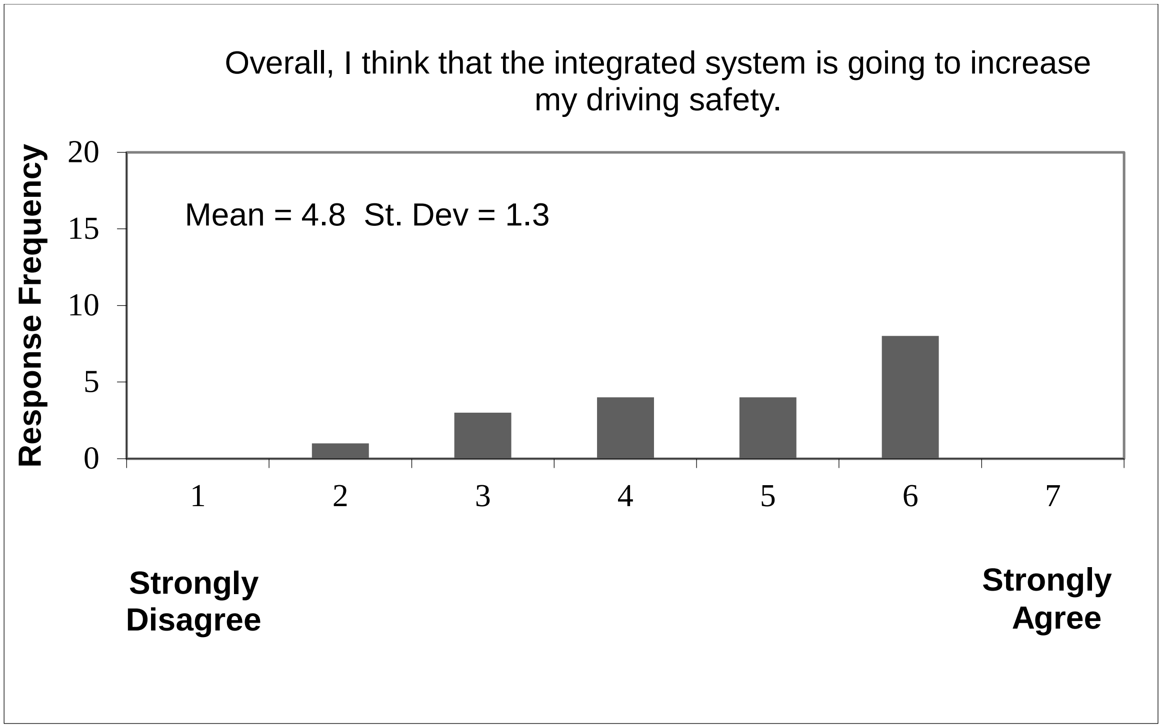


Figure 35: Perceived safety benefit of the integrated system

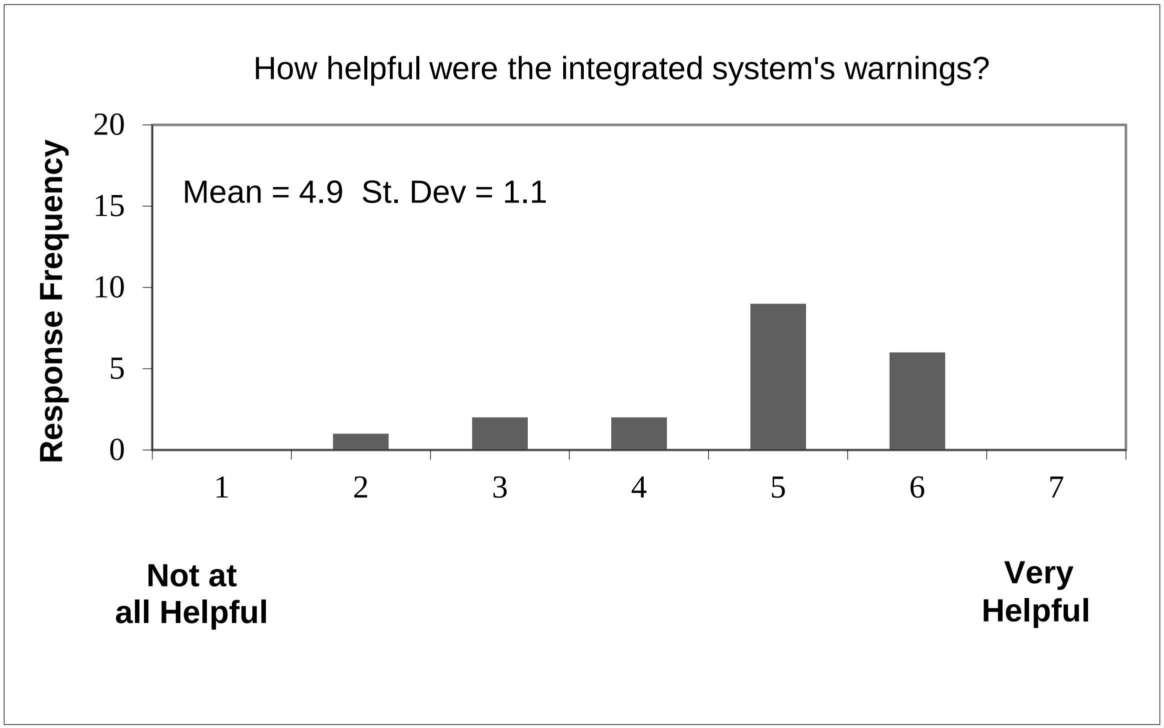


Figure 36: Perception of the integrated system’s warnings helpfulness

Assessment of Driving Skills

As part of the post-drive questionnaires, teens and one of their parents were asked to assess the teens' driving skills on a number of dimensions. Teens and their parents were asked the same questions though they completed the questionnaires separately. Selected questions and results are presented below. The complete list of questions as well as summary statistics are presented in Appendix B.

Both experimental and control group teens agreed that they were good drivers prior to the beginning of the FOT. Further, overall their parents shared their assessment (Figure 37). When asked whether or not they (their teens) were good drivers after completing their participation in the FOT, the mean rating improved for all groups except the control group teens whose mean rating remained unchanged (Figure 38).

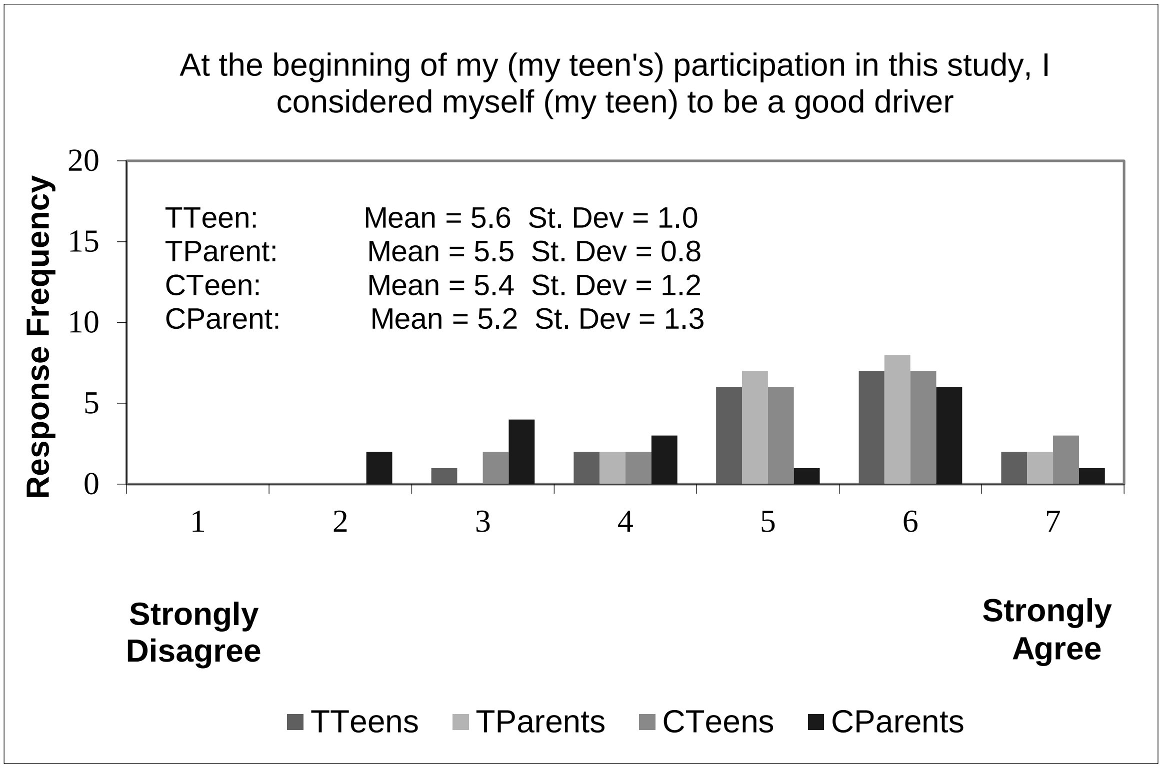


Figure 37: Teens' and their parents' assessments of their overall driving skill prior to participation in the FOT

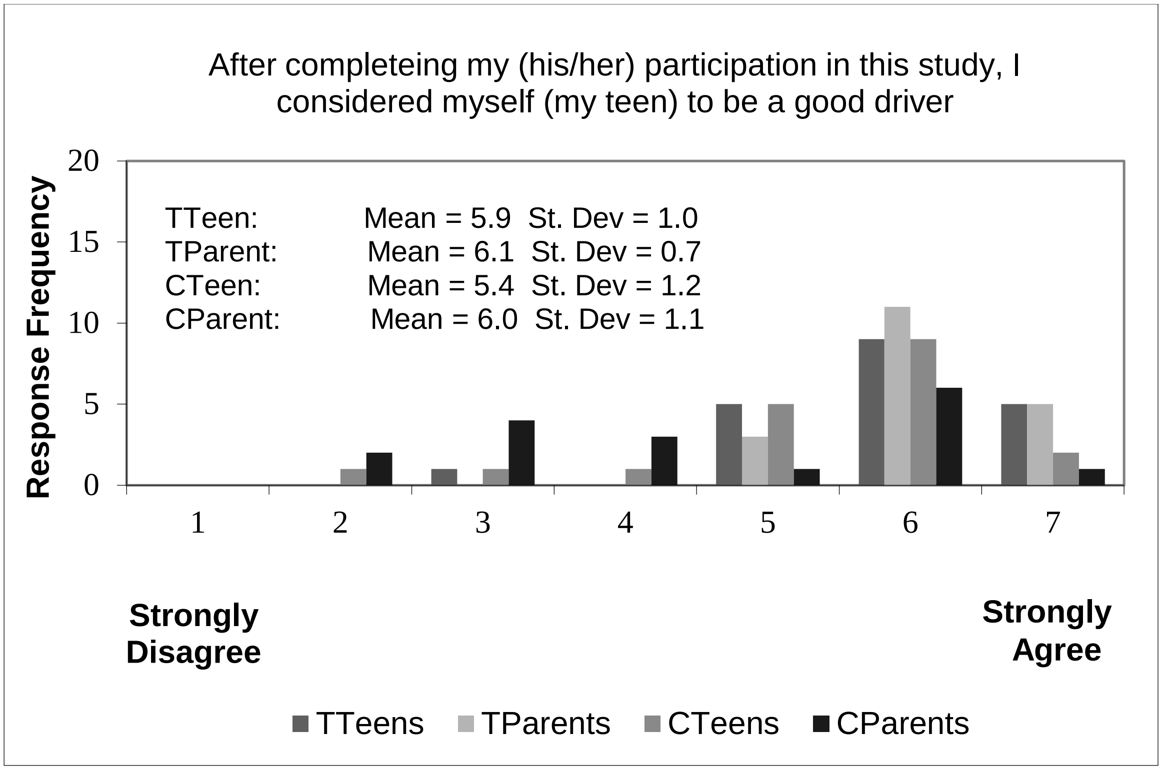


Figure 38: Teens' and their parents' assessments of their overall driving skill after participation in the FOT

When asked specifically about the attributes that make for a good driver (e.g., being in control of the vehicle at all times, maintaining safe following distances, and proper lane position), teens in both driver groups as well as their parent rated their driving behavior well (Figure 39 –Figure 41). For each factor it is interesting to note, that the mean teen rating for each driver group is higher than the corresponding mean parent group rating. Teens as well as their parents reserved their lowest ratings for the consistency with which they drove the posted speed limit as well as their ability to not be distracted by secondary tasks while driving. On both of these dimensions, for each driver group, teens rated their behavior lower than their parents (Figure 42 and Figure 43.

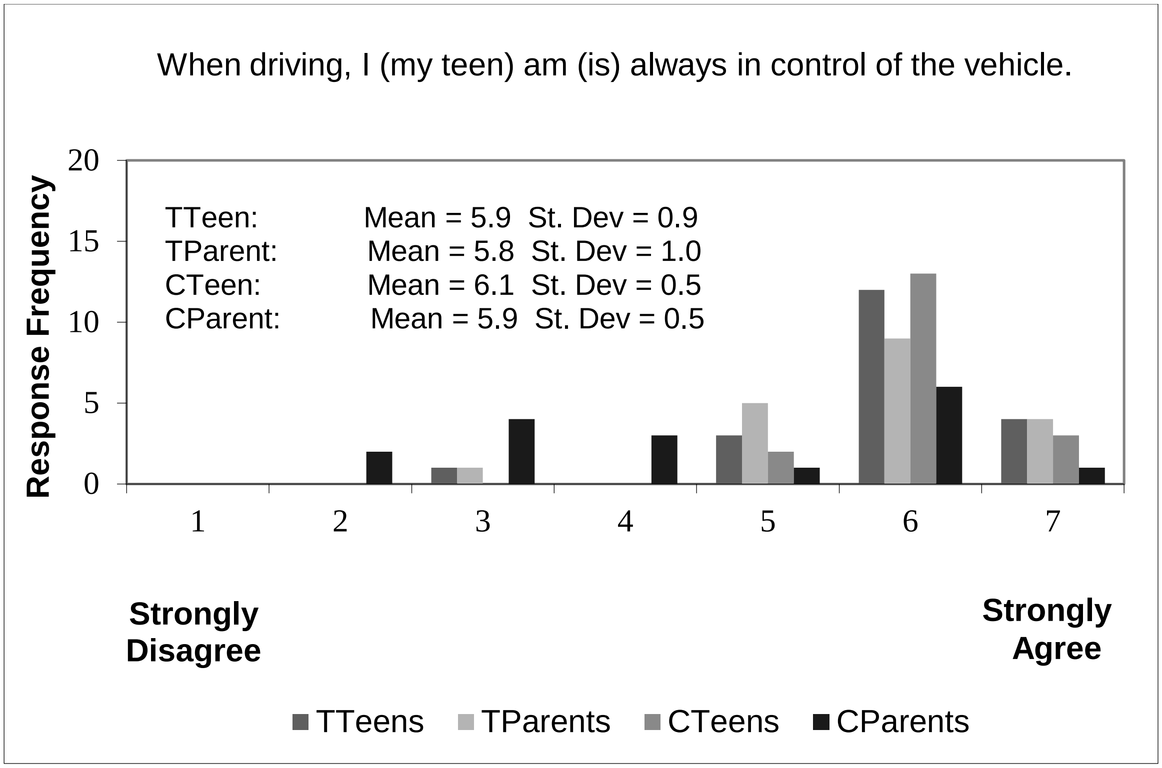


Figure 39: Teens' and their parents' assessment of the teens' ability to maintain control of the vehicle

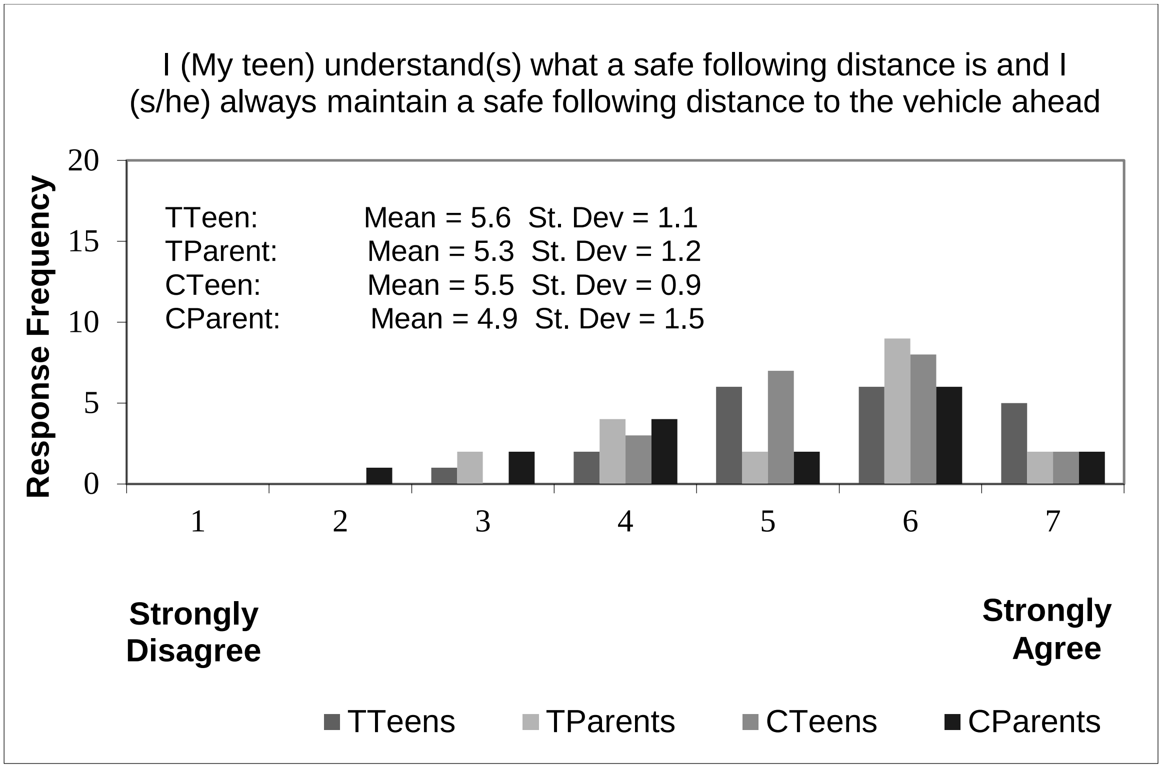


Figure 40: Teens' and their parents' assessments about driving at a safe following distance

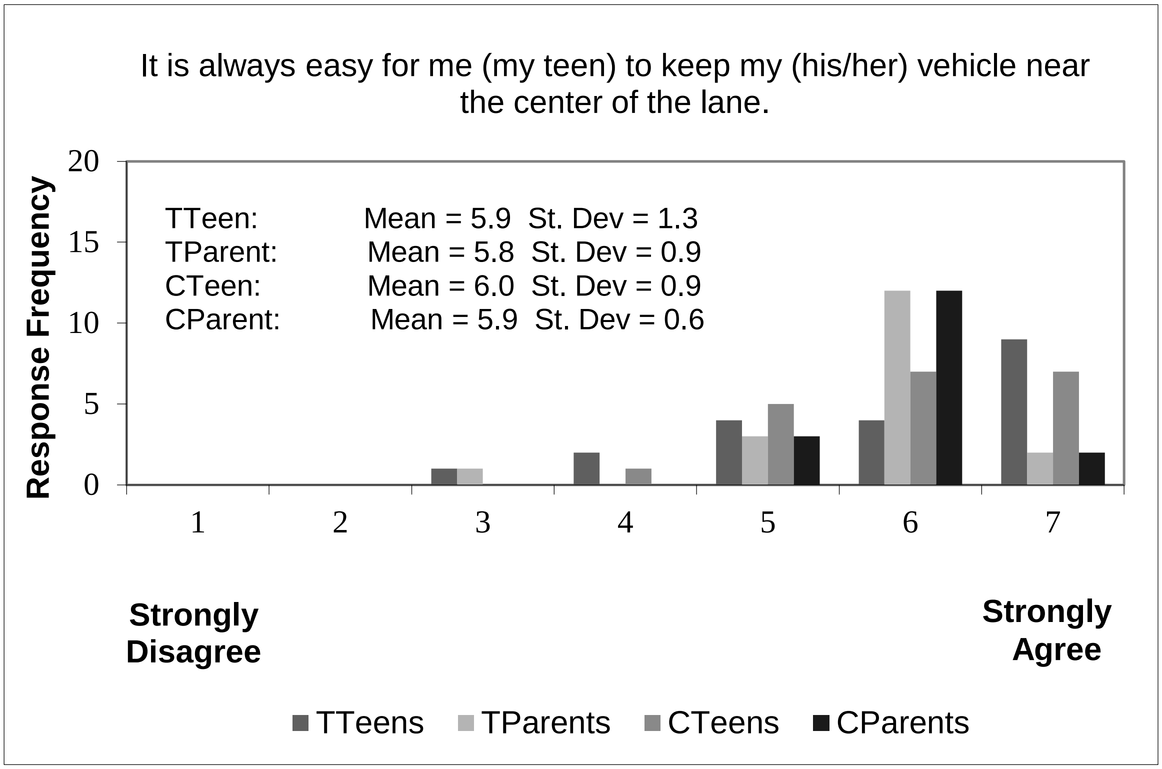


Figure 41: Teens' and their parents' assessments about lane keeping behavior

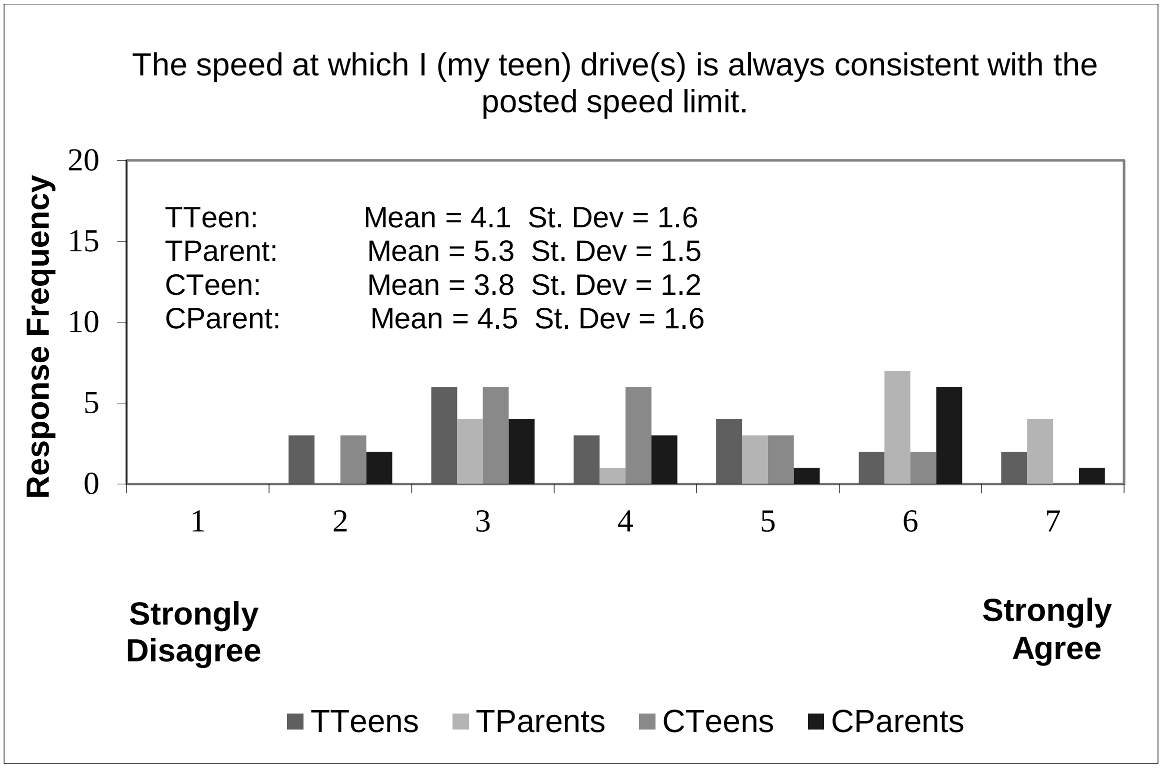


Figure 42: Teens' and their parents' assessments about driving at the posted speed limit

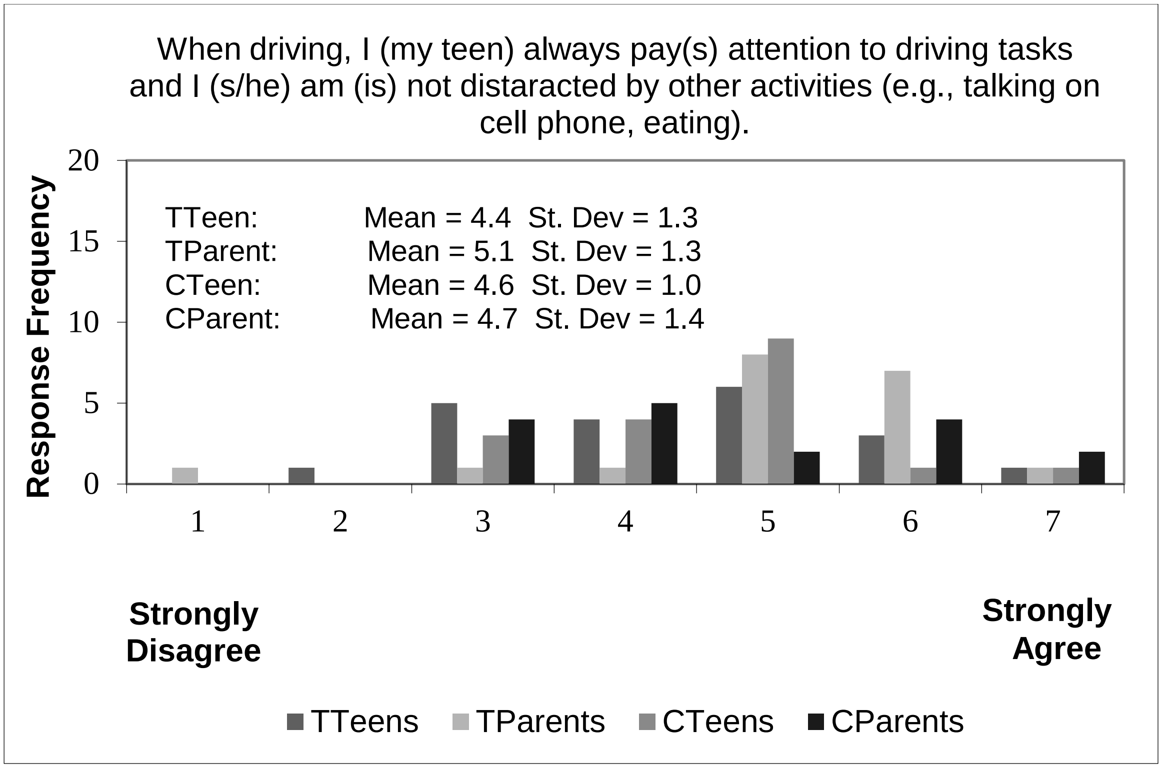


Figure 43: Teens' and their parents' assessments about driving while distracted

Conclusions

Despite being over represented in motor vehicle crashes, the presence of an integrated crash warning system had few effects on key indicators of teen driving behavior. The results are generally comparable to previous findings for an adult cohort under similar conditions (Sayer et al., 2010).

Secondary Tasks

- Teens were not involved in a secondary task in 50% of the video clips that were reviewed, and the most frequently occurring secondary task for teens was talking to a passenger (22% of all clips).
- Teens in the experimental group were no more likely than those in the control group to engage in secondary tasks when the system was providing warnings. This suggests that the presence of the integrated crash warning system had no effect, positive or negative, on teens' decisions to engage in secondary tasks.
- Female teens were 1.3 times as likely to be involved in a secondary task while driving than their male counterparts.
- Teens were 1.6 times as likely to elicit a warning if they were not engaged in a secondary task as compared to when they were engaged in a secondary task. This suggests that drivers may be selecting less demanding driving conditions in which to engage in secondary tasks (self-regulation).

Lateral Control

- The lane departure frequency for teens in the control group was 24% higher than for the experimental group.
- During the treatment period, the teens in the experimental group were five times as likely to use their turn signals than teens in the control group.
- Teens' lane departure frequency was higher at night and on limited access roads.
- When male teens departed the lane, they stayed outside of the lane longer than female teens.
- In the presence of a vehicle in the adjacent lane, teens traveled farther outside of the lane than when an adjacent vehicle was not present.
- Teens were twice as likely to use their turn signals on limited access roads compared to surface streets.

Longitudinal Control

- Teens maintained time headways below 1.0 s more frequently in the treatment and post-treatment period than in the baseline period. This result was consistent between experimental and control groups.
- Teens maintained shorter headways in dense and moderate traffic as well as on surface streets.
- Teens had lower levels of deceleration in response to longitudinal conflicts in the treatment and post-treatment periods than for the baseline period.
- Teens had high levels of deceleration in response to forward conflicts in denser and moderate traffic volumes, as well as on surface roads.
- The rate of hard braking maneuvers did not differ between driver groups or exposure periods. In other words, the presence of the integrated crash warning system had no apparent impact on the frequency of hard braking maneuvers.
- There were no significant effects on drivers' reaction time to forward conflicts observed for any conditions.
- Teens had significantly lower rates of forward collision warning in the baseline period as compared to the treatment and post-treatment periods.

Subjective Responses

- Teens found the integrated system's warnings to be helpful and said they believed that such a system would increase their driving safety.
- Sixty percent of teens reported that their driving behavior changed as a result of the integrated collision warning system, where most reported changes involved drifting less often and maintaining better lane position.
- Eighty-five percent of teens reported that they did not rely on the integrated system.
- Overall, teens were satisfied with the integrated system and rated it favorably for both usefulness and satisfaction.
- Blind spot detection was rated the highest, followed by the lane departure warnings.
- Teens rated forward collision warning least favorably.

Summary

The presence of an integrated crash warning system had limited effects on several key indicators of teen driving behavior. However, this overarching result is similar to that for an adult cohort. Thus, despite being over represented in motor vehicle crashes, teens don't appear to respond much differently than their adult counterparts from an integrated collision warning system. While some, limited safety positive effects were observed with teens, they were generally comparable to those effects observed with an adult cohort population.

The presence of the integrated collision warning systems did not affect teens' decisions to engage in secondary tasks. Furthermore, engaging in a secondary task was no more likely to result in a collision warning than when not engaged in a secondary task. In fact, teens were 1.6 times less likely to receive a collision warning while engaged in a secondary task when not engaged in a secondary task. This result might be explained/attributed to drivers' selecting less demanding conditions in which to engage in secondary tasks (Funkhouser and Sayer, 2012).

The presence of the integrated warning system did have some safety positive effects on lateral control of the vehicle by teen drivers. Specifically, teens experiencing the integrated warning system had 24% fewer lane departures when compared to the control group – and the reduction in lane departures was most pronounced while the integrated warning system was activated (during the treatment phase as opposed to the baseline or post-treatment periods). In addition, teens in the treatment group were five times more likely to use their turn signals when performing lane changes.

The presence of the integrated warning system resulted in mixed effects for teens relative to the longitudinal control of the vehicle. The frequency of maintaining headways below 1.0 seconds actually increased for teens in the treatment and post-treatment periods, and teens maintained shorter headways in higher density traffic and on surface streets. However, the levels of deceleration required in response to longitudinal conflicts decreased (i.e., improved) in response to the integrated warning system in the treatment period for teens– and the effect continued into the post-treatment period.

Lastly, teen drivers, like their adult cohorts, generally offered a favorable impression of the integrated collision warning system. Most reported the system to be helpful and that it would improve their driving safety. The majority reported that the presence of the system changed they driving behavior, but that they did not become reliant on the system. The teens' rating of the individual system components was almost identical to that provided by the adult cohorts. Specifically, the blind spot and lateral warning systems were preferred over the forward collision warning portion of the integrated system.

Overall, at least for the system tested, the behavioral and subjective responses of teen drivers to the integrated collision warning system was very similar to that of an adult cohort. While there are some specific safety-positive effects, they were not as prevalent as one might hypothesized or hoped for given teens' overrepresentation in motor vehicle crashes.

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Appendix A: Summary of Light-Vehicle Post-Drive Questionnaire Responses

Question	Anchors	Mean	St Dev.
How helpful were the integrated system's warnings?	1=Not at all helpful, 7=Very helpful	4.9	1.1
Overall, I think that the integrated system is going to increase my driving safety.	1=Strongly disagree, 7=Strongly agree	4.8	1.3
Driving with the integrated system made me more aware of traffic around me and the position of my car in my lane	1=Strongly disagree, 7=Strongly agree	5.4	1.3
The integrated system made driving easier.	1=Strongly disagree, 7=Strongly agree	4.5	1.6
Overall, I felt that the integrated system was predictable and consistent	1=Strongly disagree, 7=Strongly agree	4.2	1.5
I was not distracted by the warnings	1=Strongly disagree, 7=Strongly agree	4.4	1.9
Overall, how satisfied were you with the integrated system?	1=Very dissatisfied, 7=Very satisfied	5.0	1.2
Overall, I received warnings . . .	1=Too frequently, 7=Never	3.9	1.3
I always understood why the integrated system provided me with a warning.	1=Strongly disagree, 7=Strongly agree	4.6	1.6
I always knew what to do when the integrated system provided a warning.	1=Strongly disagree, 7=Strongly agree	5.1	1.4
The auditory warnings got my attention.	1=Strongly disagree, 7=Strongly agree	6.0	1.5
I always understood why the integrated system provided me with an auditory warning.	1=Strongly disagree, 7=Strongly agree	5.2	1.6
The auditory warnings were not annoying.	1=Strongly disagree, 7=Strongly agree	3.7	2.2

Question	Anchors	Mean	St Dev.
The seat vibration warnings got my attention	1=Strongly disagree, 7=Strongly agree	6.1	1.1
I always understood why the integrated system provided me with a seat vibration	1=Strongly disagree, 7=Strongly agree	5.7	1.3
The seat vibration warnings were not annoying.	1=Strongly disagree, 7=Strongly agree	4.9	2.0
The brake pulse warnings got my attention.	1=Strongly disagree, 7=Strongly agree	5.6	1.9
I always understood why the integrated system provided me with a brake pulse warning.	1=Strongly disagree, 7=Strongly agree	4.9	1.7
The brake pulse warning was not annoying.	1=Strongly disagree, 7=Strongly agree	4.1	2.1
The yellow lights in the mirrors got my attention.	1=Strongly disagree, 7=Strongly agree	5.1	1.9

Question	Anchors	Mean	St Dev.
I always understood why the integrated system provided me with a yellow light in the mirror.	1=Strongly disagree, 7=Strongly agree	6.9	0.4
The yellow lights in the mirrors were not annoying.	1=Strongly disagree, 7=Strongly agree	6.9	0.5
The integrated system gave me warnings when I did not need them (i.e., nuisance warnings)	1=Strongly disagree, 7=Strongly agree	5.8	1.2
Overall, I received nuisance warnings . . .	1=Too frequently, 7=Never	3.5	1.1
The integrated system gave me a left/right hazard warning when I did not need one.	1=Strongly disagree, 7=Strongly agree	3.6	1.8
The integrated system gave me a left/right drift warning when I did not need one.	1=Strongly disagree, 7=Strongly agree	3.9	1.9
The integrated system gave me a hazard ahead warning when I did not need one.	1=Strongly disagree, 7=Strongly agree	5.4	1.8
The integrated system gave me a sharp curve warning when I did not need one.	1=Strongly disagree, 7=Strongly agree	2.9	1.7
The integrated system display was useful.	1=Strongly disagree, 7=Strongly agree	4.6	1.7
The mute button was useful.	1=Strongly disagree, 7=Strongly agree	4.5	1.9
The volume adjustment control was useful.	1=Strongly disagree, 7=Strongly agree	4.9	1.7
Would you like to have the integrated system in your personal vehicle?	1=Definitely not, 5=Definitely would	3.4	1.2

Appendix B: Summary of Driver Assessment Questions

		Experimental Teens		Experimental Parents		Control Teens		Control Parents	
Question	Anchors	Mean	St Dev.	Mean	St Dev.	Mean	St Dev.	Mean	St Dev.
At the beginning of my participation in this study, I considered myself to be a good driver.	1=Strongly disagree, 7=Strongly agree	5.6	1.0	5.5	0.8	5.4	1.2	5.2	1.3
After completing my participation in this study, I consider myself to be a good driver.	1=Strongly disagree, 7=Strongly agree	5.9	1.0	6.1	0.7	5.4	1.2	6.0	1.0
When driving, I am always in control of the vehicle	1=Strongly disagree, 7=Strongly agree	5.9	0.9	5.8	1.0	6.1	0.5	5.9	0.9
The speed at which I drive is always consistent with the posted speed limit.	1=Strongly disagree, 7=Strongly agree	4.1	1.6	5.3	1.5	3.8	1.2	4.6	1.7
I always accelerate the vehicle smoothly.	1=Strongly disagree, 7=Strongly agree	5.1	1.3	5.3	0.8	4.4	1.2	5.5	1.2
When braking, I always apply the proper level of brake pressure.	1=Strongly disagree, 7=Strongly agree	5.6	1.2	5.4	0.8	5.4	1.4	5.6	1.1
I understand how to approach and to take curves at a safe speed.	1=Strongly disagree, 7=Strongly agree	5.7	1.2	5.2	1.0	5.8	0.8	5.4	1.2

Question	Anchors	Experimental Teens		Experimental Parents		Control Teens		Control Parents	
		Mean	**St Dev.**	**Mean**	**St Dev.**	**Mean**	**St Dev.**	**Mean**	**St Dev.**
When I am in a moving vehicle, I always wear my seatbelt.	1=Strongly disagree, 7=Strongly agree	7.0	0.2	6.9	0.3	6.9	0.3	7.0	0.0
I understand what a safe following distance is and I always maintain a safe following distance to the vehicle ahead of me.	1=Strongly disagree, 7=Strongly agree	5.6	1.1	5.3	1.2	5.5	0.9	5.0	1.5
It is always easy for me to keep my vehicle near the center of the lane.	1=Strongly disagree, 7=Strongly agree	5.9	1.3	5.8	0.9	6.0	0.9	5.9	0.5
Once I begin to make a lane change, I am never surprised to find a vehicle in my blind spot.	1=Strongly disagree, 7=Strongly agree	5.9	1.5	4.9	1.0	5.8	0.9	5.6	1.0
When merging onto the highway, I am always confident in selecting a gap and adjusting my speed accordingly.	1=Strongly disagree, 7=Strongly agree	5.9	1.2	5.0	1.3	6.3	0.7	5.7	0.8
When driving, I always pay attention to driving tasks and I am not distracted by other activities (e.g., talking on my cell phone, eating).	1=Strongly disagree, 7=Strongly agree	4.4	1.3	5.1	1.3	4.6	1.0	4.7	1.4