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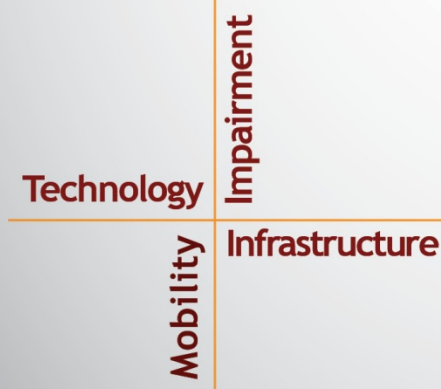
National Surface Transportation
Safety Center for Excellence

Driver Coach Study

Using Real-time and Post Hoc Feedback to
Improve Teen Driving Habits

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EXECUTIVE SUMMARY

INTRODUCTION

The purpose of this study was to test whether teenage drivers could benefit from receiving real-time and post hoc feedback on their driving performance. Novice teenage drivers have the highest rates of fatalities and injuries on U.S. roadways compared to any other age group. This experimental research was conducted to see if presenting novice teenage drivers and their parents with feedback on teen driving performance could decrease rates of crash/near-crash (CNC) involvement. This study drew on prior research suggesting that real-time feedback and post hoc driver feedback are important in creating lasting change in driver behavior.

METHOD

Ninety-two newly licensed teens had their vehicles instrumented with a data acquisition system (the Virginia Tech Transportation Institute's MiniDAS) and received driving feedback in the form of a light and a tone when a potentially risky behavior was detected. Behaviors, such as swerving, speeding, lane changing without a turn signal, hard braking, hard turning, and fast starts, were used to determine when feedback was administered. Feedback continued for six months and then was turned off for one month (in the seventh month) to determine if risky behaviors returned after feedback stopped. These data were compared to a separate study (the Supervised Practice Driving Study [SPDS]) of 90 teenage drivers in the same geographic location who did not receive feedback. Parental involvement was examined by tracking which teen/parent groups checked the website and which did not.

The research objectives of this report were as follows:

- Objective 1: Do real-time and post hoc feedback reduce rates of CNC, elevated g-force events, and coachable events involvement for teen drivers as compared to a control group not receiving such feedback?
- Objective 2: What are the time trends of each type of coachable event and how did parental involvement influence this behavior?
- Objective 3: Are there any observable unintended consequences for the teens who received feedback versus the teens who did not receive feedback?
- Objective 4: After the feedback was turned off, did the occurrence of CNC and coachable events increase?
- Objective 5: What does driving performance feedback show to be the greatest behavioral error for teens? How often do they engage in these erroneous behaviors?
- Objective 6: What human characteristics (e.g., personality, risk-taking propensity, etc.) have an impact on driving performance?

RESULTS

The Driver Coach Study (DCS) results suggest (see Figure ES1) that real-time and post hoc feedback produce a relative reduction in the rate of CNC involvement, but only when the parent is logging in to the website. If parents do not log in to the website to review the coachable events, real-time and post hoc feedback do not improve CNC rates.

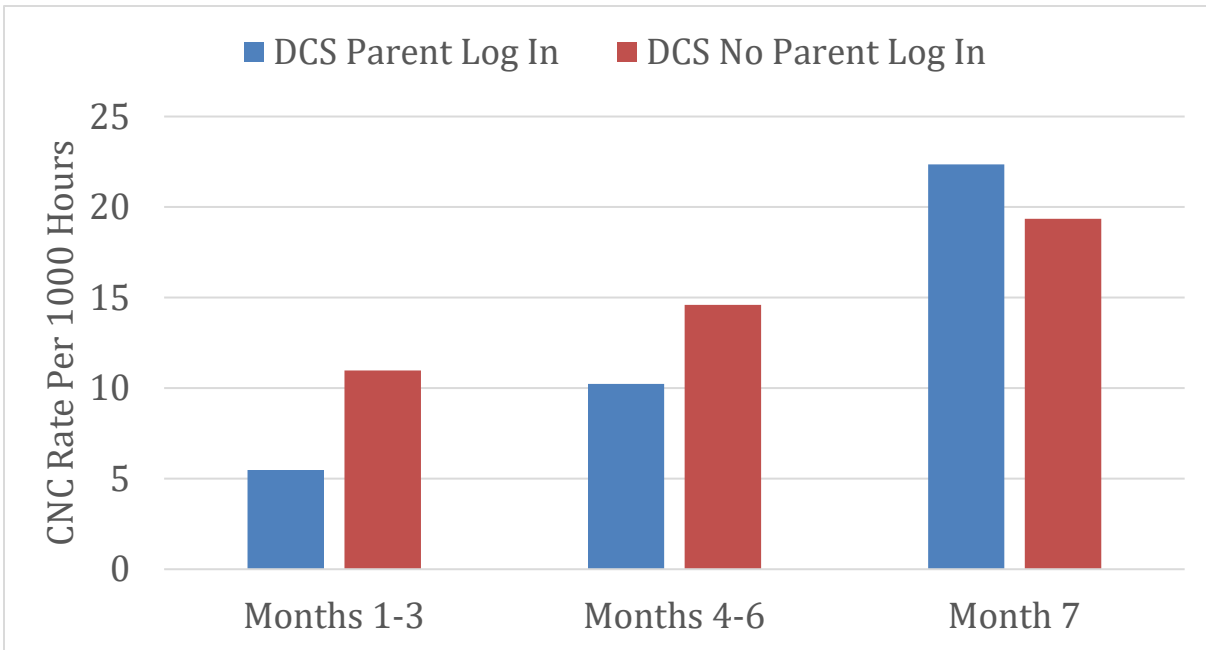


Figure ES1. Graph. CNC rates for teens whose parents’ monitored website versus teens whose parents did not monitor website.

The analyses of these data also indicated that once feedback was turned off in Month 7, teen CNC rates returned to baseline levels. This result suggests that 6 months of feedback is not enough time to instill safe driving habits in novice drivers. This result also suggests that parental involvement in driver education must continue through the independent driving phase, for as long as possible, to improve teen CNC rates.

CONCLUSIONS

These results support previous research on monitoring and feedback, which suggest that parental involvement is critical in improving teen driving safety. These results also support current Graduated Driver’s Licensing (GDL) policies and provide research-based evidence that these policies should be strengthened to save teenage drivers’ lives.

TABLE OF CONTENTS

LIST OF FIGURES.....	v
LIST OF TABLES.....	vii
LIST OF ABBREVIATIONS AND SYMBOLS	viii
CHAPTER 1. INTRODUCTION.....	1
CHAPTER 2. METHODS	5
PARTICIPANTS.....	5
EQUIPMENT	5
<i>Vehicles</i>	5
<i>Instrumentation</i>	6
<i>MiniDAS Communication</i>	9
<i>Installation Software</i>	10
<i>Maintenance Software</i>	11
DATA COLLECTION	11
DATA RETRIEVAL	11
MEASURES.....	11
<i>Real-Time Driver Feedback</i>	12
<i>Post Hoc Driver Feedback</i>	15
<i>Driver Coach Participant Website</i>	16
DATA REDUCTION.....	19
<i>Reduction Process</i>	19
SURVEYS, QUESTIONNAIRES, AND INTERVIEWS	22
DATA QUALITY ASSURANCE AND QUALITY CONTROLS.....	22
CHAPTER 3. RESULTS.....	25
OBJECTIVE 1	26
<i>CNC Rates</i>	26
<i>Coachable Events</i>	28
OBJECTIVE 2	29
OBJECTIVE 3	32
OBJECTIVE 4	33
OBJECTIVE 5	36
OBJECTIVE 6	40
CHAPTER 4. DISCUSSION	45
CHAPTER 5. FUTURE WORK	47
CHAPTER 6. CONCLUSIONS	49
CHAPTER 7. RECOMMENDATIONS	51
APPENDIX A. TEENAGE CRASH RATES IN VIRGINIA	53
REFERENCES	55

LIST OF FIGURES

Figure 1. Photo. MiniDAS compared to standard AA battery.	7
Figure 2. Photo. MiniDAS installation location.	8
Figure 3. Photo. Compressed video image of driver view and forward view. Driver’s face is blurred to protect driver privacy.....	9
Figure 4. Diagram. MiniDAS epoch creation.....	14
Figure 5. Diagram. Epoch processing decision tree.....	15
Figure 6. Screenshot. Weekly summary email example.....	16
Figure 7. Screenshot. Driver Coach Report Card tab.....	17
Figure 8. Screenshot. Driver Coach Event Player tab.....	18
Figure 9. Screenshot. Information displayed under video player. Speed, brake status, and acceleration information would update in real-time as video was played.	18
Figure 10. Screenshot. Coaching notes for lane departure.	18
Figure 11. Screenshot. Event summary including example of fly-out question mark text of individual coaching tips for distractions/errors.....	19
Figure 12. Screenshot. Participant comment feature.	19
Figure 13. Screenshot. Epoch list generated by the MinDR tool.....	20
Figure 14. Screenshot. MinDR software tool where coding of each coachable event occurred.	21
Figure 15. Diagram. Timeline of the DCS data collection period.	25
Figure 16. Graph. CNC rate for DCS teens whose parents monitored the website, those DCS teens whose parents did not monitor the website, and SPDS teens (no feedback).....	26
Figure 17. Graph. Percentage of participants that were involved in 0 CNC events, 1 to 3 CNC events, and 4+ CNC events.	27
Figure 18. Graph. Coachable event rates for teens whose parents’ monitored website versus those whose parents did not monitor website.....	28
Figure 19. Graph. Coachable event rates for four feedback types: hard braking, hard cornering, fast start, and exceeding speed across the first six months of driving.....	30
Figure 20. Graph. Coachable events by trigger type for teens of parents who never logged in to website.	31
Figure 21. Graph. Coachable events by trigger type for teens of parents who logged in to website.....	31
Figure 22. Graph. Lane departure warning over months since licensure by teenagers whose parents logged in to website versus teenagers whose parents did not log in to website.....	32

Figure 23. Graph. CNC rates for teens whose parents monitored website versus those teens whose parents did not monitor website.	33
Figure 24. Graph. Coachable event rates for teen drivers whose parents logged in to website and those who did not log in to website.	34
Figure 25. Graph. Coachable event rates by trigger type for teenagers with parents who did not log in to website.	35
Figure 26. Graph. Coachable event rates by trigger type for teenagers with parents who logged in to website.	35
Figure 27. Graph. Rate of driver errors for teens by parental monitoring versus no parental monitoring.	36
Figure 28. Graph. Rate of errors by type for teens with no parental monitoring.	37
Figure 29. Graph. Rate of errors by type for teens with parental monitoring.	37
Figure 30. Graph. Types of behavior occurring for speed selection errors.	38
Figure 31. Graph. Types of distractions occurring for distraction errors.	38
Figure 32. Graph. Types of hazards occurring for hazard perception errors.	39
Figure 33. Graph. GDL violations over time.	39
Figure 34. Graph. Parental agreement (percentage of responses) with the statement, “I would recommend DCS to my friends.”	40
Figure 35. Graph. Parental agreement (percentage of responses) with the statement, “I believe my teen drives more safely than if he/she had not participated in the study.”	41
Figure 36. Graph. Parental agreement (percentage of responses) with the statement, “DCS has helped me teach my teen to drive more safely.”	42
Figure 37. Graph. Teen agreement (percentage of responses) with the statement, “I would recommend the DCS to my friends.”	43
Figure 38. Graph. Teen agreement (percentage of responses) with the statement, “I drive more safely now, than I would have, if I had not participated in this study.”	44

LIST OF TABLES

Table 1. Description and distribution of vehicle types. 6

Table 2. Description and distribution of vehicle ages. 6

Table 3. MiniDAS specifications..... 7

Table 4. Trigger types and thresholds..... 13

Table 5. QA/QC measures..... 23

Table 6. Number of teen drivers by gender and by parental login status. 25

Table 7. Contrast estimate results. Poisson random intercept regression model results. 27

Table 8. Contrast estimate results. Poisson regression results for coachable event analysis. 28

Table 9. Contrast estimate results. Poisson regression results for coachable event analysis. 34

LIST OF ABBREVIATIONS AND SYMBOLS

ADHD	Attention Deficit Hyperactivity Disorder
AHC	Advanced Health Check
CAN	Controller Area Network
CDMA	Code Division Multiple Access
CNC	Crash/Near-Crash
DAS	Data Acquisition System
DCS	Driver Coach Study
DMV	Department of Motor Vehicles
DSP	Digital Signal Processor
GDL	Graduated Driver's Licensing
GPS	Global Positioning System
GUI	Graphical User Interface
IRB	Institutional Review Board
IVDR	In-Vehicle Data Recorder
LED	Light-Emitting Diode
MiniDAS	Miniature Data Acquisition System
MinDR	Miniature Data Reduction Tool
NHTSA	National Highway Traffic Safety Administration
NTDS	Naturalistic Teenage Driving Study
OBD-II	On-Board Diagnostic System II
QA/QC	Quality Assurance/Quality Control
SDHC	Secure Digital High Capacity
SMS	Short Message Service
SPDS	Supervised Practice Driving Study
VDOT	Virginia Department of Transportation
VMT	Vehicle Miles Traveled
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

Motor vehicle crashes remain the leading cause of fatalities among teens in the United States.^(1,2) In 2010, drivers between the ages of 15 and 20 made up 6.4% of all licensed drivers, yet comprised 14% of drivers in all crashes.⁽³⁾ Teens' fatal crash involvement is about four times that of adult drivers.⁽⁴⁾

Teen drivers have a high crash risk rate for two reasons: inexperience and immaturity. As first-time drivers, teens have not had time to develop the driving skills required to reduce crash risks.⁽⁵⁾ The developmental stage of adolescence can also pose challenges for teen drivers' safety. This translates to difficulty managing distractions while driving and, accordingly, poor judgment that leads to higher crash risk. Additionally, adolescents engage in risk-taking and sensation-seeking activities more frequently than mature adults.⁽⁶⁾

Research shows that certain risk factors are directly related to increased teen driver crash involvement. Speeding, which may also qualify as sensation seeking, is one such risk factor that has been implicated in about one-third of all fatal teen crashes from 2000 to 2011. In fact, there was a slight increase in teen speeding-related crashes from 2000 (30%) to 2011 (33%).⁽⁷⁾ Night driving, an environmental rather than a behavioral factor, is another known driving risk.^(8,9) Per driving mile, 16- and 17-year-old drivers are nearly three times more likely to be involved in a fatal crash at night than during the day.⁽⁴⁾

When discovering and assessing methods to mitigate teen driving risks, identification of risks leading up to crash involvement is essential. Naturalistic driving studies allow researchers to investigate teens' normal driving behavior in real-world settings. Naturalistic driving studies measure crashes, near-crashes, and elevated g-force events as indicators of unsafe driving behavior. Crashes and near-crashes (CNCs) are defined by measurable physical contact or near contact. Changes in acceleration due to late braking, swerving, fast starts, and sharp turns create elevated g-force events. Crashes and near-crashes are clearly dangerous, but it is also important to recognize the dangers associated with elevated g-force events. These events can reduce the time other drivers have to respond to these risky behaviors and increase the potential for loss of vehicle control.^(10,11)

Research with in-vehicle data recorders has shown a significant association between elevated g-force events and crashes.^(10,12) Simons-Morton, Zhang, Jackson, and Albert⁽¹³⁾ investigated the extent to which elevated g-force events predicted CNCs and found a correlation of .60 between CNCs and elevated g-force events. In addition, higher rates of elevated g-force events in a prior month increased the risk of a crash in the subsequent month.⁽¹³⁾ These studies support the idea of using elevated g-force events as a proxy measure for crashes and risky driving.

Furthermore, naturalistic driving studies have indicated that elevated g-force events among teens that contributed to crash and near-crash rates have remained much higher than their parents' after 18 months of driving.⁽¹⁴⁾ Interestingly, the low rate of risky driving in the presence of adult passengers suggests that it is possible for teens to drive in a less-risky manner.⁽¹⁵⁾

Measuring g-forces and other naturalistic driving metrics is accomplished largely with the use of in-vehicle technology. Developments in in-vehicle technology have opened the doors for more

complex and innovative ways to collect data on driver behavior and driving environments that can potentially improve our knowledge about how teens learn to drive. In-vehicle data recorders (IVDR) and/or data acquisition systems (DASs) can come equipped with a wide variety of sensors and monitors. Common features include accelerometers, video cameras, Global Positioning Systems (GPSs), audio recording, cellular network connectivity, vehicle sensor integration (speed, RPM, throttle, turn signals), ignition interlock systems, and passenger occupancy sensors.⁽¹⁶⁾ Combined, these can provide a detailed record of driver performance, but do not necessarily modify current or future driver behavior.

However, when feedback is incorporated into in-vehicle monitoring technology, the opportunity arises to intervene in, and possibly alter, potentially risky driver behavior. Feedback can be administered as real-time in-vehicle alerts, or as delayed, post hoc feedback on past driving performance. Real-time feedback technologies include in-vehicle display screens, audio or voice alerts, or haptic feedback, such as vibrations, to signal the driver.⁽¹⁶⁾ Examples of delayed feedback include reports on driving behavior and video clips, which can be made available via the vehicle display, a website, or a smartphone application.

In-vehicle monitoring systems with feedback that are not video-based have been shown to have the least-promising results for improving teen driver safety. Toledo and Lotan⁽¹⁷⁾ investigated the effects of an IVDR that measured two-dimensional acceleration, speed, and used GPS tracking. These variables were used to identify and classify 20 risky-driving maneuvers, including hard braking, high accelerations, and excessive speed. Real-time alerts were given to the driver when one of these maneuvers was recognized. A risk index for each trip was calculated and categorized as cautious, moderate, or aggressive. This delayed feedback was presented in a monthly report that displayed the risk index for every trip that month. While initial use of the system had a significant positive impact on the participant's driving safety, by the fifth month the effect had disappeared.⁽¹⁷⁾

Another similar non-video-based IVDR was investigated, but this version also detected seat belt use and could determine if the driver was going over the posted speed limit.⁽¹⁸⁾ Participants were assigned to one of four groups: (i) vehicle monitoring with in-vehicle alert and immediate website notification (alert and Web); (ii) vehicle monitoring with in-vehicle alert and conditional website notification (alert then Web, but if the driver corrected the error no notification was sent to the website); (iii) vehicle monitoring with website notification but no in-vehicle alert (Web only); and (iv) vehicle monitoring with no in-vehicle alert and no website access (control group). In-vehicle feedback consisted of an audible buzz immediately following an elevated g-force event, a continuous buzz when seat belts were not used, and sequential beeps when speeding. Results indicated that elevated g-force events did not decrease significantly for treatment groups. Additionally, speeding behavior was either not affected at all (Web only) or the effect diminished over time (alert then Web, alert and Web). Seat belt use increased significantly for all treatment groups.⁽¹⁸⁾ Results from all three of these studies appear to suggest that IVDRs without video recording do not lead to safer driving behaviors.

IVDRs with event-triggered video have been assessed in several studies and show more promise. Systems with real-time driver feedback paired with delayed event feedback provided to parents have been shown to reduce the frequency of high g-force events such as sudden acceleration, braking, and turning.⁽¹⁹⁾ These effects are stronger for drivers who are already considered high

risk.^(20,21,22) Additionally, supporting evidence shows that providing driving report cards, real-time feedback, and parental access to event-triggered videos may reduce the frequency of g-force events, while immediate feedback without the reporting aspect may not.⁽¹⁹⁾

In addition to addressing the risk factors related to teen driving, we recognize the positive impact of parenting on teen driving behaviors.^(23,24,25,26) Parents play a crucial role in teen driving safety; they act as gatekeepers by enforcing regulations such as Graduated Driver's Licensing (GDL) laws, providing access to vehicles, and teaching teens to drive. Risky driving behaviors such as speeding and not using seat belts are more frequent among teens with low levels of parental monitoring and restrictions.^(27,28) Furthermore, several studies have indicated that parents are often not aware of their teens' risky driving behaviors (e.g., driving under the influence, not using seat belts, driving with drunk passengers).^(27,28) Thus, parents need to become more involved in teen driving to further enhance safety. Supervised practice driving and parental monitoring during both the learner's permit and early licensure phases provide critical opportunities to do so. However, little is known about supervised practice driving and parental monitoring.

Using knowledge gained from prior research suggesting that the presence of adult passengers, parental involvement, and feedback both real-time and post hoc, are essential to see lasting change in driver behavior, the Driver Coach Study (DCS) examined whether providing real-time and post hoc feedback improved teen driving performance. The real-time feedback was provided to teens in the form of a light and an audible three-tone alert followed by a computer-voiced description of the maneuver when a potentially risky event occurred (i.e., elevated g-force event was detected). The post hoc feedback component was delivered to both parents and teens via a website, thus enabling parental involvement to continue during the early independent driving phase after the supervised practice driving phase. Real-time and post hoc feedback were turned off in Month 7, but data continued to be collected to determine if risky behaviors returned after feedback was turned off. These data were compared to a separate study that served to function as the control group, the Supervised Practice Driving Study (SPDS), which followed 90 teenage drivers in the same geographic location who did not receive any form of feedback.

This report will discuss the research methods used and statistical analyses performed to better understand the following research objectives:

- Objective 1: Do real-time and post hoc feedback reduce rates of CNC, elevated g-force events, and coachable events involvement for teen drivers as compared to a control group not receiving such feedback?
- Objective 2: What are the time trends of each type of coachable event and how did parental involvement influence this behavior?
- Objective 3: Are there any observable unintended consequences for the teens who received feedback versus the teens who did not receive feedback?
- Objective 4: After the feedback was turned off, did the occurrence of CNC and coachable events increase?

- Objective 5: What does driving performance feedback show to be the greatest behavioral error for teens? How often do they engage in these erroneous behaviors?
- Objective 6: What human characteristics (e.g., personality, risk-taking propensity, etc.) have an impact on driving performance?

CHAPTER 2. METHODS

PARTICIPANTS

Ninety-two parent and newly permitted novice teen driver dyads from Bedford County, Roanoke County, and Montgomery County, Virginia, were recruited as primary drivers to have their personal vehicles instrumented. Teens received their learner's permit no more than two weeks prior to initial paperwork and instrumentation. The areas from which participants were recruited represented a wide variety of driving environments, including urban, suburban, and rural drivers. Additionally, teens clinically diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) were excluded from the study, as research suggests that these teens have higher rates of risky behavior than non-ADHD teens.^(29,30,31,32) Drivers were recruited primarily through advertisements at Virginia Department of Motor Vehicles (DMVs) service center locations in the area; this allowed for the recruitment of study-eligible teens in the short window of time after the receipt of their learner's permit. Recruitment flyers were also distributed at high schools in the area, and researchers were present during some parent/teen safe driving nights held by schools. Finally, advertisements were also placed in local newspapers to recruit participants.

Forty-six female and 46 male teens between the ages of 15.5 and 16.1 years of age were recruited. Teens and parents received \$25 each at the initial paperwork and instrumentation appointment. Teens received an additional \$750 for their participation, spread out across the study in approximately six-month increments: \$250 after completing the six-month learner's permit questionnaires, \$250 after completing questionnaires upon receipt of the provisional driving license, and \$250 after the vehicle was de-instrumented and the final questionnaires were complete.

Two participants completed initial paperwork, but vehicle sensor issues disqualified their vehicles for instrumentation. Some drivers ended their participation early for other reasons, such as a move from the study area. Five participants which ended their participation early were replaced. A total of 97 recruited parent-teen dyads made up the study's subject pool. Additionally, when a parent and teen agreed to participate, they were asked if there were any other common drivers of the instrumented vehicle that would consent to allowing us to use their driving data. If they said yes, a secondary driver consent form was given to the parent to pass on to these drivers for consideration, resulting in the recruitment of 45 secondary drivers. These secondary participants were over the age of 18 and typically were parents or older siblings.

EQUIPMENT

Vehicles

Since the DAS instrumentation utilized a vehicle's On-Board Diagnostics System II (OBD-II) port, eligible vehicles for this study typically had to be no older than model year 1996. Some vehicles from 1995 had an OBD-II port and were considered on a case-by-case basis (Table 1 and Table 2).

Of the 97 parent-teen dyads with driving data, 19 participants had instrumentation moved from their original vehicle to a different vehicle in the middle of the study due to vehicle crashes or a

new primary vehicle for the teen. Thus, the total number of vehicles instrumented in this study was 116.

Table 1. Description and distribution of vehicle types.

Vehicle type (all)	Number
Sedan	50
Truck	2
SUV	30
Hatchback/wagon	17
Van	17
Total Vehicles	116

Table 2. Description and distribution of vehicle ages.

Vehicle ages (all)	Number
1995–1999	12
2000–2005	57
2006–2010	31
2011–2015	16
Total Vehicles	116

Instrumentation

The DCS utilized the Virginia Tech Transportation Institute’s (VTTI’s) state-of-the-art DAS, the MiniDAS (Figure 1). It employs ninth-generation hardware and software, capitalizing on proprietary advancements that VTTI has developed over a period of 20 years drawing upon in-house DAS design experience.



Figure 1. Photo. MiniDAS compared to standard AA battery.

The MiniDAS was designed to be unobtrusive and easily installed in most vehicles in under 60 minutes via a connection to a vehicle’s OBD-II interface port (Table 3).

Table 3. MiniDAS specifications.

Size	6.5” × 5” × 1.75”
Video Channels	Forward roadway (640 × 480) Driver (640 × 480)
Storage	128 GB removable SDHC card
Hardware	GPS: speed, latitude, longitude, heading 3-axis accelerometer: X, Y, Z 3-axis gyroscope: X, Y, Z Magnetometer Cellular modem Audio warning capability Microphone (8000 Hz, 8-bit, mono) Infrared (IR) illumination (nighttime video visibility) Customizable color LED to provide visual warnings to driver Incident pushbutton

Key Features	Self-contained, single unit
	Small installation footprint
	Single OBD-II cable installation
	Controller Area Network (CAN) variable collection (speed, RPM, brake, turn signals, etc.)
	Real-time detection of safety epochs
	Lane departures
	Hard turns
	Hard braking
	Excessive speed
	Swerve
Epoch and continuous data collection	
Expandable to work with Wi-Fi, Bluetooth, or CAN modules	

The unit was mounted approximately 3 inches from the bottom of the vehicle’s windshield, near the vehicle center line (Figure 2). A cable was routed for power and vehicle network data collection between the OBD-II port and the MiniDAS.



Figure 2. Photo. MiniDAS installation location.

The MiniDAS utilizes a Linux kernel, which runs on an ARM processor. One Digital Signal Processor (DSP) is dedicated to RoadScout (video-based lane tracking and monitoring software developed by VTTI). Under normal driving conditions, the 128 GB Secure Digital High Capacity (SD) card is capable of collecting three to four months of video, sensor, and network data before capacity constraints necessitate a card swap.

The MiniDAS digital video subsystem records two separate views: the forward roadway view and the driver view. Frame numbers are overlaid on the lower left portion of the video feed, allowing for synchronization of the video streams. A static frame of compressed DCS video data is shown in Figure 3.



Figure 3. Photo. Compressed video image of driver view and forward view. Driver's face is blurred to protect driver privacy.

MiniDAS Communication

In the course of the DCS, the MiniDAS utilized a Code Division Multiple Access (CDMA) cellular transmission protocol to upload captured epoch (see Measures section) video and data files. Additionally, the system uploaded Short Message Service (SMS) messages upon system startup at the beginning of each trip that provided data on the status of the system, including variables such as vehicle battery condition and storage space remaining on the drive. These SMS messages assisted in identifying potential communication, file system, or power issues that might have affected the MiniDAS's operation.

Furthermore, once every 20 trips, or 10 days—whichever occurred first—the system uploaded an Advanced Health Check (AHC). The AHC consisted of an encrypted compressed archive which contained:

- Various system, configuration, and diagnostic logs, including lists of collected file names, file creation dates, and file sizes contained within a directory.
- A static snapshot of camera video views from each trip to enable identification of camera hardware problems or obstructions.
 - These static snapshots were also fed into VTTI's driver identification software, which allowed for the identification and assignment of a driver ID to the individual trip file in question.

The MiniDAS also features an incident pushbutton. This button allowed the participant to manually create an epoch. When the button was pushed, a 30-second window of video and audio recording began. At the time of vehicle instrumentation, participants were asked to press the

button following a crash or at any other time that they experienced an interesting or important safety-related event that they wanted to highlight or flag. Via the audio recording, they were able to offer an explanation of the circumstances surrounding the event that they had experienced. This flag was useful in identifying the particular continuous trip file containing the event for internal retrieval and review once the hard drive containing the continuous trip data was retrieved.

Installation Software

VTTI's specialized proprietary software, InstallerWare, was used when performing vehicle instrumentations. InstallerWare is a Windows graphical user interface (GUI) program that guides installation technicians through the configuration and setup of the MiniDAS instrumentation. The program features tabs and pages with required fields that the installation technician populates, as described below.

InstallerWare Pages

Vehicle Information: The technician entered the participant ID (previously generated upon completion of informed consent) to select the vehicle associated with the participant. The technician then entered the following: make, model, and year of the vehicle, plus odometer reading, battery condition, tire pressure, and tread depth information.

Vehicle Photos: The technician then took pre-installation photographs of eight angles of the subject vehicle and uploaded them into InstallerWare. These photographs provided pre- vs. post-install, and installation vs. de-installation vehicle condition comparison points. As such, the photos allowed for the identification of any damage that might have occurred as a result of an unreported crash.

Barcodes: The technician scanned or typed the barcodes of installed components (MiniDAS unit, SD card, and, if applicable, the vehicle network box).

Install Hardware: The technician entered vehicle-specific and installation-specific information including the following: vehicle width, MiniDAS installation height, and MiniDAS offset from vehicle centerline.

Install Software: InstallerWare then integrated the technician-entered measurements into the software package configuration for the vehicle. Any vehicle-specific packages (vehicle network files, etc.) were also pulled from the database along with base operating system files and auxiliary programs and were installed on the MiniDAS SD card.

Testing: The technician manually performed several test procedures to ensure proper system operation and collection. Brake lights, turn signals, and headlights were all tested to ensure that their status was being properly collected. Additionally, the cell modem signal strength and MiniDAS communication ability were tested.

Calibration: InstallerWare then displayed a static image of the driver and forward camera views. This enabled the technician to ensure both video feeds were operational and unobstructed.

Additionally, the technician set the position of the vehicle hood line in the forward view. This was necessary for proper RoadScout (lane tracking and monitoring software) operation.

Maintenance Software

VTTI's propriety software, MaintenanceWare, was used for maintenance activities, primarily SD card swaps on instrumented vehicles. MaintenanceWare provided some of the same functionality as InstallerWare in terms of installation of software packages and the testing of cellular modem and camera views (refer to section above).

DATA COLLECTION

Participants were enrolled for up to 16 months (9 months of the learner's permit phase and at least 7 months of early licensure). As mentioned above, real-world driving data were collected using VTTI's MiniDAS system, which includes sensors, accelerometers, GPS, and cameras that collect objective driving measures (e.g., lane departures, speed, braking intensity, and yaw), audio, and video with multiple camera views (forward and driver's face; see Figure 3). A special note about video and audio data: video data were collected for all the months of data collection while audio data were collected only during the learner's permit phase.

DATA RETRIEVAL

A VTTI researcher was tasked with maintaining a cycle of data retrieval appointments with all participants. A convenient, central location in each participant's general locale was selected for these appointments. Data retrieval occurred every two to three months for each participant to prevent the SD cards from exceeding their available storage space. The researcher used MaintenanceWare to connect to the DAS via Wi-Fi. The SD card containing data was retrieved from the vehicle and a new SD card was installed in the DAS. Participants were paid \$10 for each appointment to compensate them for their time and travels. Appointments typically took about 30 minutes.

At every SD card swap, various data were checked to ensure that proper collection was taking place. The researcher recorded notes of missing or unusual variables and discussed these issues with appropriate hardware and software groups at VTTI. If needed, additional appointments were scheduled to remedy data issues. Examples of potential issues were nonfunctional camera or audio, poor cellular communication, and improper sensor readings (e.g., left turn is collected as right turn).

MEASURES

Throughout this study we collected data and analyzed various measures. For the ease of reader comprehension, we are providing the definitions up front.

Epoch – A generic term for a captured safety-related event that has not yet been verified by a trained data coder.

Safety-related incidents – These include CNCs, elevated g-force events, and coachable events as described below.

Crashes and near-crashes – CNCs are defined by measurable physical contact or near contact. We define crash as “any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated.” This includes contact with other vehicles, roadside barriers, objects on or off the roadway, pedestrians, cyclists, or animals. In contrast, near-crash means “any circumstance that requires a rapid evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash.” Trained data coders also determined and documented whether the driver was “at-fault” or “not at fault” for each event.

Elevated g-force events – Changes in acceleration due to late braking, swerving, fast starts, and sharp turns create elevated g-force events. Crashes and near-crashes are clearly dangerous, but it is also important to recognize the dangers associated with elevated g-force events. These events can reduce the time other drivers have to respond to these risky behaviors and increase the potential for loss of vehicle control. Research with in-vehicle data recorders has shown a significant association between elevated g-force events and crashes.⁽¹⁰⁾ These events were directly comparable to the control study (SPDS) participants.

Coachable events – Coachable events are events where the teen driver exceeded a vehicle kinematic threshold (e.g., braked above -0.55 g, see Table 5), which were reviewed and confirmed to be valid events by trained coders. These events were used to provide feedback to the teen driver and parent (refer to Figure 5 for diagram of epoch processing). These events are not comparable to the SPDS control study because these types of events were not identified and/or coded for the SPDS study. Trained data coders also evaluated whether the event was due to an error made by the driver (driver fault), made by another driver (driver not at-fault), or was, in fact, good conduct by the participant (e.g., braked hard to avoid a pedestrian in the roadway).

Real-Time Driver Feedback

Once the teen participant reached the feedback phase of the study—approximately two weeks¹ from their anticipated independent licensure date—in-vehicle real-time feedback was enabled. The aim of the two-week pre-licensure feedback period was to allow parents and teens time to gain familiarity with the system alerts and to experience the thresholds together prior to the teen beginning the independent driving period.

The MiniDAS had triggers for each of the following driving maneuvers and thresholds as shown in Table 4.

¹ The pre-license feedback phase varied because not all participants received their license at exactly 9 months.

Table 4. Trigger types and thresholds.

Trigger Type	Threshold Values	Alert Speech Component
<i>Longitudinal Deceleration</i>	≤ -0.55 g longitudinal deceleration for duration of ≥ 500 ms. Minimum speed threshold of 5 m/s (11 mph).	“ <i>Hard Brake</i> ”
<i>Longitudinal Acceleration</i>	≥ 0.35 g longitudinal acceleration for duration of $\geq 1,000$ ms. No minimum speed threshold.	“ <i>Fast Start</i> ”
<i>Lateral Acceleration</i>	± 0.5 g lateral acceleration with a minimum speed of ± 5 m/s (11 mph).	“ <i>Hard Turn</i> ”
<i>Lane Departure Warning</i>	Crossing a lane line without turn signal activated. Minimum speed of 20.1 m/s (45 mph). Only right lane crossings due to inattention/distraction were considered coachable.	“ <i>Lane Crossing</i> ”
<i>Swerve</i>	The derivative of yaw rate defines one complete cycle of a sine waveform and exceeds 19 deg/s/s with similar signed slopes within 2,000 ms. The minimum speed is 8.94 m/s (~20 mph).	“ <i>Swerve</i> ”
<i>Speed</i>	≥ 75 mph for a duration of greater than 15,000 ms.	“ <i>Speeding</i> ”
<i>Critical Incident Button</i>	Boolean input initiated by participant when the participant felt his/her safety had been compromised in some way.	None

When a participant exceeded a trigger threshold, the MiniDAS provided an audible three-tone alert, followed by a speech descriptor of the trigger type. For example, “beep-beep-beep-Hard Brake.” The light-emitting diode (LED) indicator light, located behind the translucent housing of the incident button, simultaneously flashed amber three times. The MiniDAS then created an epoch of the triggered event. The epoch consisted of video, audio, and sensor data of approximately 8 seconds prior to the triggered event to 8 seconds after the triggered event (Figure 4). This epoch was then uploaded to a secure VTTI server via the cellular network.

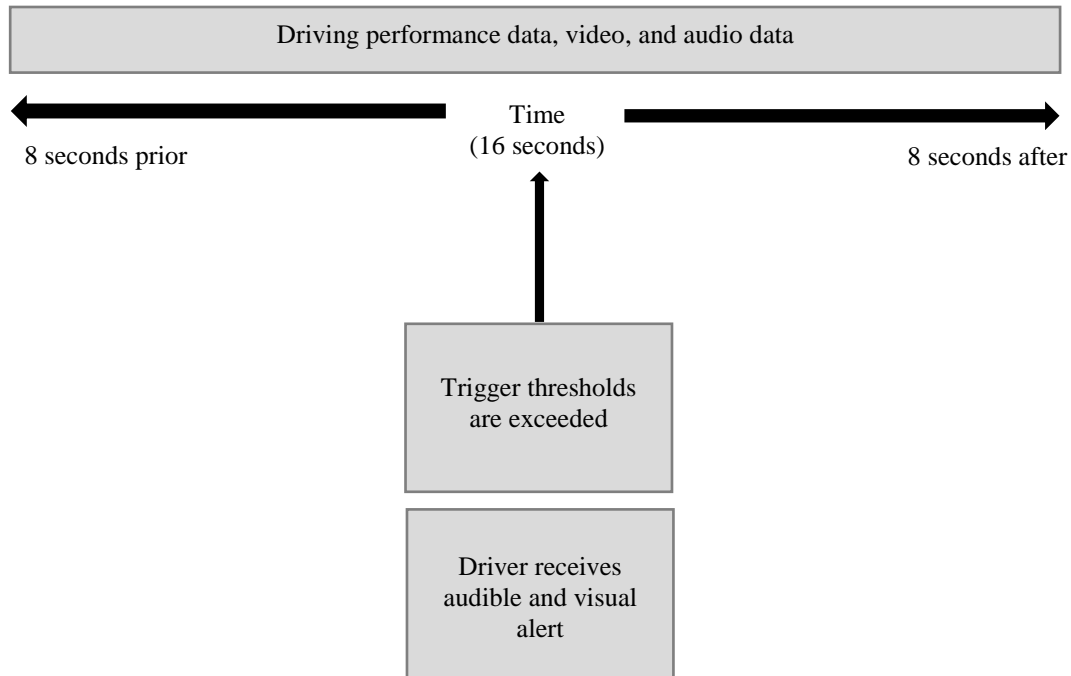


Figure 4. Diagram. MiniDAS epoch creation.

Once the epoch was received by the VTTI server, it was placed in the data reduction (MinDR) queue. There, reductionists reviewed the event and determined if the teen participant was driving during the epoch and whether it was valid or invalid (Figure 5). If valid, the epoch was assigned an epoch type: Safety Incident, Near-Crash, or Crash. Reductionists then determined if the participant was (a) at-fault, (b) not at-fault, or (c) not at-fault plus displayed good conduct during the epoch in question. Reductionists also determined if the epoch was recommended for coaching. Additionally, they coded categorical variables (roadway type, traffic flow, seat belt usage, lighting, and weather) that served to describe the environment in which the epoch occurred. Finally, they coded any driver distractions, errors, or GDL policy violations that were present during the epoch (see Data Reduction for details).

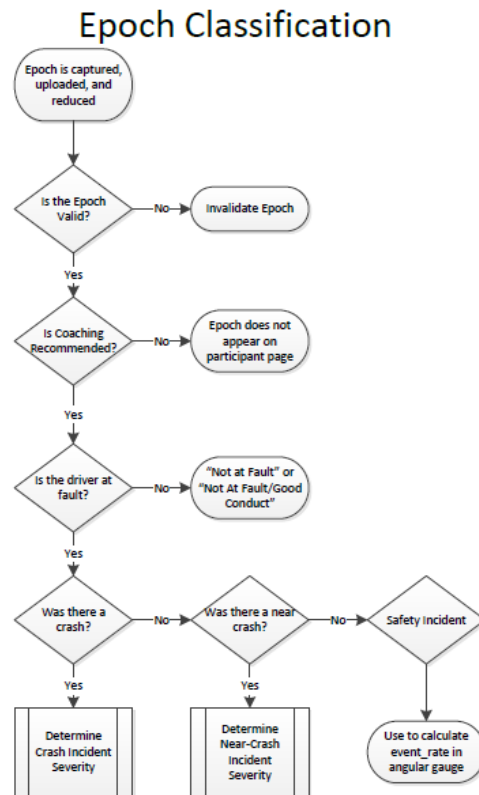


Figure 5. Diagram. Epoch processing decision tree.

Post Hoc Driver Feedback

Post hoc feedback was provided to the participants who had received their independent driving license. Prior to being uploaded to the website, any epochs that were coded as recommended for coaching were further quality checked by a data reduction manager and were released to the participant Web page early morning each Wednesday, on a weekly basis, at which time they were available for parent and teen review. An email was also sent to the parents of teens who had coaching-recommended epochs during a release week, notifying them that there were new events available for review on the participant webpage (Figure 6).

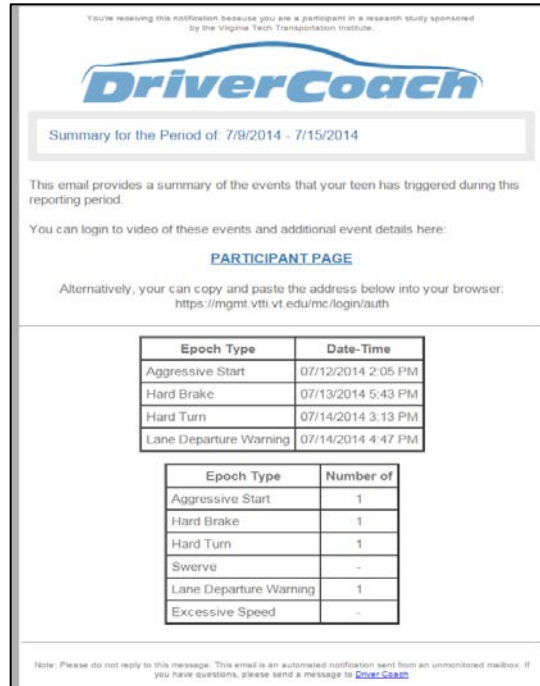


Figure 6. Screenshot. Weekly summary email example.

Driver Coach Participant Website

Upon notification that the teen participant would be receiving their independent driver's license within one to two weeks, the research team sent an email to the parent participant (and teen, if applicable) containing instructions, credentials, and a link to the VTTI-developed participant website: drvcoach.vtti.vt.edu. The site consisted of two main tabs: Report Card and Event Player.

Report Card Tab

The Report Card tab allowed participants to view graphs and information about the type and frequency of events generated over the course of a four-week period (Figure 7). It included information concerning the following:

- How often the teen participant was determined to be at-fault in the captured events.
- The number and types of safety events that the teen generated during the current release week and the three prior release weeks.
- The number of lane departures the teen generated during the current release week and three prior release weeks.
- The number and type of potential GDL violations the teen had during the current release week.



Figure 7. Screenshot. Driver Coach Report Card tab.

Event Player Tab

The Event Player tab consisted of a Safety Event Inbox, which contained a list of coaching recommended events, ordered by most to least recent. The list contained information regarding the event occurrence time, the event type, and the rating (at-fault, not at-fault, good conduct). A participant could select an event within the inbox and play video of the event in the video player located to the right of the inbox. Vehicle speed and lateral and longitudinal acceleration values updated in real-time as the video played. Below the video player was further information concerning the event type, fault assignment, lighting conditions, traffic flow, roadway type, weather, seat belt usage, and any distractions or errors present during the event. Additionally, there were standard coaching notes displayed, based upon the trigger type. Participants were also able to leave a comment in response to the selected epoch (Figure 8 through Figure 12).

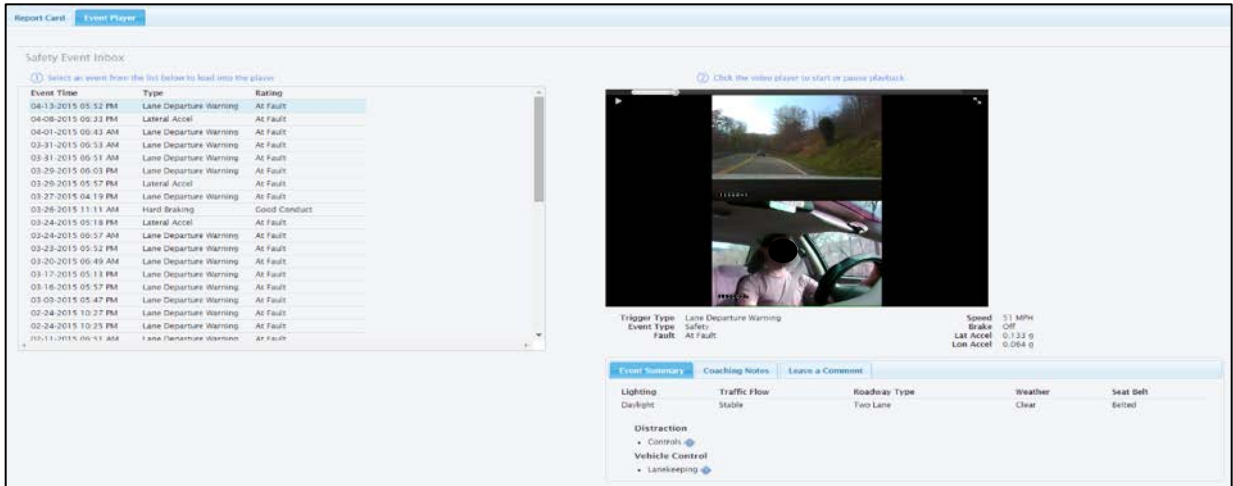


Figure 8. Screenshot. Driver Coach Event Player tab.

Trigger Type	Lane Departure Warning	Speed	51 MPH
Event Type	Safety	Brake	Off
Fault	At Fault	Lat Accel	0.133 g
		Lon Accel	0.064 g

Figure 9. Screenshot. Information displayed under video player. Speed, brake status, and acceleration information would update in real-time as video was played.

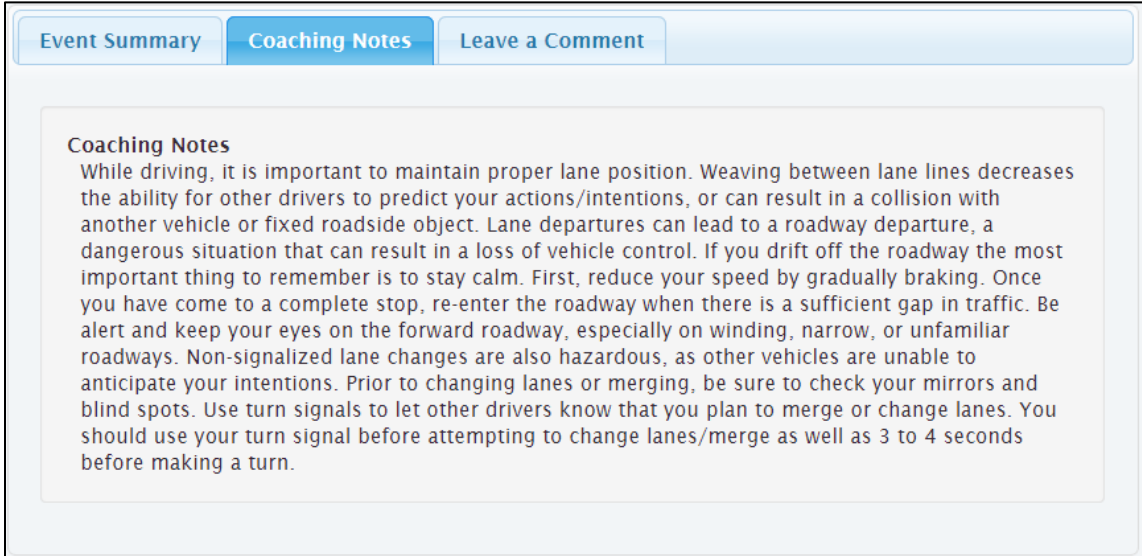


Figure 10. Screenshot. Coaching notes for lane departure.

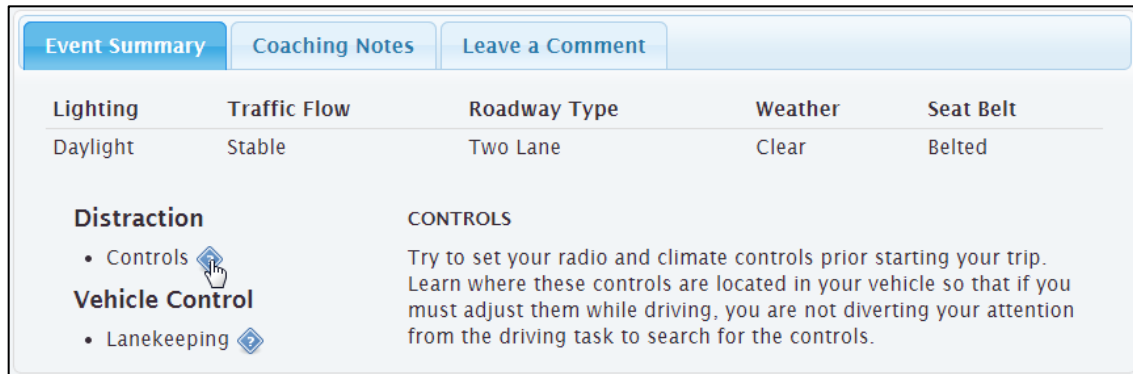


Figure 11. Screenshot. Event summary including example of fly-out question mark text of individual coaching tips for distractions/errors.

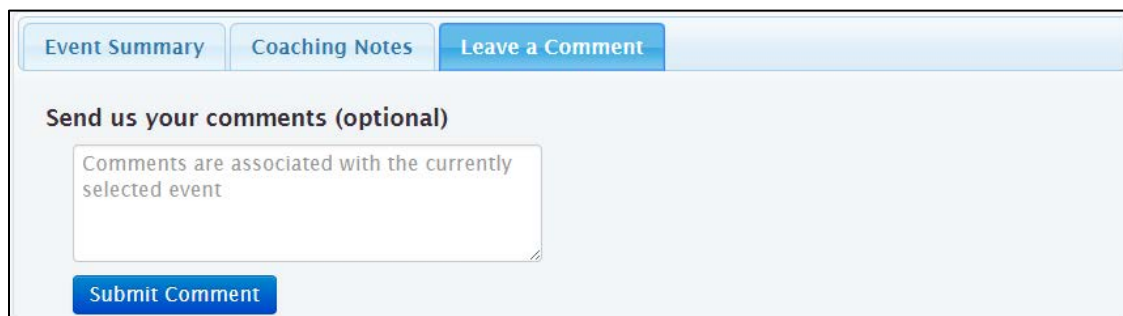


Figure 12. Screenshot. Participant comment feature.

DATA REDUCTION

Reduction Process

Data reductionists were assigned to the Driver Coach project by the Data Reduction Group Leader. The reductionists were trained on the reduction tool using a formal protocol. Data reduction was completed using MinDR, a VTTI proprietary Web-based software that allows for epochs, which are automatically uploaded, to be queued and ready for rapid reduction. Figure 13 is an image of the epoch list within MinDR.

Epoch List							Logout
Epoch ID	Vehicle	Trigger Type	Org Name	Occurrence Date	Upload Date	Feedback Date	
216216	299282	LANE_DEPARTURE_WARNING	Driver Coach BEDFORD field site	Apr 14, 2015 02:53:00 PM	Apr 15, 2015 09:45:55 AM	Jan 00, NaN 00:00:00 AM	
216214	299328	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 15, 2015 08:33:03 AM	Apr 15, 2015 08:42:23 AM	Jan 00, NaN 00:00:00 AM	
216213	298920	LANE_DEPARTURE_WARNING	Driver Coach PULASKI field site	Apr 15, 2015 08:15:34 AM	Apr 15, 2015 08:24:57 AM	Jan 00, NaN 00:00:00 AM	
216208	299188	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 14, 2015 06:22:13 PM	Apr 15, 2015 07:32:22 AM	Oct 14, 2014 00:00:00 AM	
216207	299103	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 15, 2015 07:18:59 AM	Apr 15, 2015 07:25:52 AM	Sep 03, 2014 00:00:00 AM	
216205	299327	LATERAL_ACCEL	Driver Coach ROANOKE field site	Apr 13, 2015 04:46:21 PM	Apr 15, 2015 07:17:38 AM	Dec 17, 2014 00:00:00 AM	
216204	299297	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 06:37:44 PM	Apr 15, 2015 07:02:53 AM	Jan 23, 2015 00:00:00 AM	
216203	299108	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 06:40:52 AM	Apr 15, 2015 07:09:59 AM	Feb 13, 2015 00:00:00 AM	
216202	299101	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 04:58:01 PM	Apr 15, 2015 06:54:44 AM	Sep 24, 2014 00:00:00 AM	
216201	299160	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 15, 2015 05:23:26 AM	Apr 15, 2015 07:18:18 AM	Sep 08, 2014 00:00:00 AM	
216196	152857	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 03:10:18 PM	Apr 14, 2015 06:31:54 PM	Sep 20, 2014 00:00:00 AM	
216195	152863	HARD_BRAKING	Driver Coach BLACKSBURG field site	Apr 14, 2015 06:19:12 PM	Apr 14, 2015 06:28:29 PM	Jan 05, 2015 00:00:00 AM	
216194	152857	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 03:41:01 PM	Apr 14, 2015 06:24:46 PM	Sep 28, 2014 00:00:00 AM	
216193	299198	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 08:45:22 AM	Apr 14, 2015 06:19:20 PM	Oct 14, 2014 00:00:00 AM	
216192	299257	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 13, 2015 06:59:47 AM	Apr 14, 2015 05:17:12 PM	Jan 23, 2015 00:00:00 AM	
216191	299182	LATERAL_ACCEL	Driver Coach PULASKI field site	Apr 13, 2015 02:50:55 PM	Apr 15, 2015 07:28:18 AM	Oct 01, 2014 00:00:00 AM	
216190	152858	HARD_ACCEL	Driver Coach BLACKSBURG field site	Apr 14, 2015 04:07:02 PM	Apr 15, 2015 07:16:01 AM	Oct 10, 2014 00:00:00 AM	
216189	152863	HARD_ACCEL	Driver Coach BLACKSBURG field site	Apr 11, 2015 01:27:13 PM	Apr 14, 2015 06:31:44 PM	Jan 05, 2015 00:00:00 AM	
216187	152858	EXCEEDING_MAX_SPEED	Driver Coach BLACKSBURG field site	Apr 14, 2015 04:08:59 PM	Apr 14, 2015 04:17:04 PM	Oct 10, 2014 00:00:00 AM	
216186	152858	EXCEEDING_MAX_SPEED	Driver Coach BLACKSBURG field site	Apr 14, 2015 03:43:55 PM	Apr 14, 2015 04:09:20 PM	Oct 10, 2014 00:00:00 AM	
216180	299181	LATERAL_ACCEL	Driver Coach BLACKSBURG field site	Apr 10, 2015 01:21:18 PM	Apr 14, 2015 06:02:44 PM	Sep 30, 2014 00:00:00 AM	
216178	299218	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 14, 2015 00:45:12 PM	Apr 14, 2015 05:51:05 PM	Nov 07, 2014 00:00:00 AM	
216176	318615	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 09:46:31 AM	Apr 14, 2015 09:57:41 AM	Mar 14, 2015 00:00:00 AM	
216175	299262	LANE_DEPARTURE_WARNING	Driver Coach BEDFORD field site	Apr 13, 2015 06:12:38 PM	Apr 14, 2015 10:35:02 AM	Jan 00, NaN 00:00:00 AM	
216174	299262	LANE_DEPARTURE_WARNING	Driver Coach BEDFORD field site	Apr 13, 2015 06:13:07 PM	Apr 14, 2015 09:49:38 AM	Jan 00, NaN 00:00:00 AM	
216173	299198	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 14, 2015 07:43:54 AM	Apr 14, 2015 06:22:58 PM	Oct 14, 2014 00:00:00 AM	
216172	299198	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 14, 2015 07:47:48 AM	Apr 14, 2015 08:55:26 AM	Oct 14, 2014 00:00:00 AM	
216171	299282	LANE_DEPARTURE_WARNING	Driver Coach BEDFORD field site	Apr 13, 2015 09:03:19 PM	Apr 14, 2015 09:52:46 AM	Jan 00, NaN 00:00:00 AM	
216170	299181	EXCEEDING_MAX_SPEED	Driver Coach BLACKSBURG field site	Apr 13, 2015 05:57:02 PM	Apr 14, 2015 02:45:12 PM	Sep 30, 2014 00:00:00 AM	
216169	299218	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 13, 2015 07:23:01 PM	Apr 14, 2015 07:45:46 AM	Nov 07, 2014 00:00:00 AM	
216168	299181	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 13, 2015 05:57:58 PM	Apr 14, 2015 07:43:16 AM	Sep 30, 2014 00:00:00 AM	
216167	299198	LANE_DEPARTURE_WARNING	Driver Coach BLACKSBURG field site	Apr 13, 2015 06:57:36 PM	Apr 14, 2015 07:45:06 AM	Oct 14, 2014 00:00:00 AM	
216165	299108	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 06:43:51 AM	Apr 15, 2015 06:43:03 AM	Feb 13, 2015 00:00:00 AM	
216163	299108	LANE_DEPARTURE_WARNING	Driver Coach ROANOKE field site	Apr 14, 2015 00:14:23 AM	Apr 15, 2015 07:10:45 AM	Feb 13, 2015 00:00:00 AM	

Figure 13. Screenshot. Epoch list generated by the MinDR tool.

Reductionists were instructed to select an event from the epoch list to begin its data reduction process. Reductionists were then taken to a page to complete the reduction for each epoch, as shown in Figure 14.

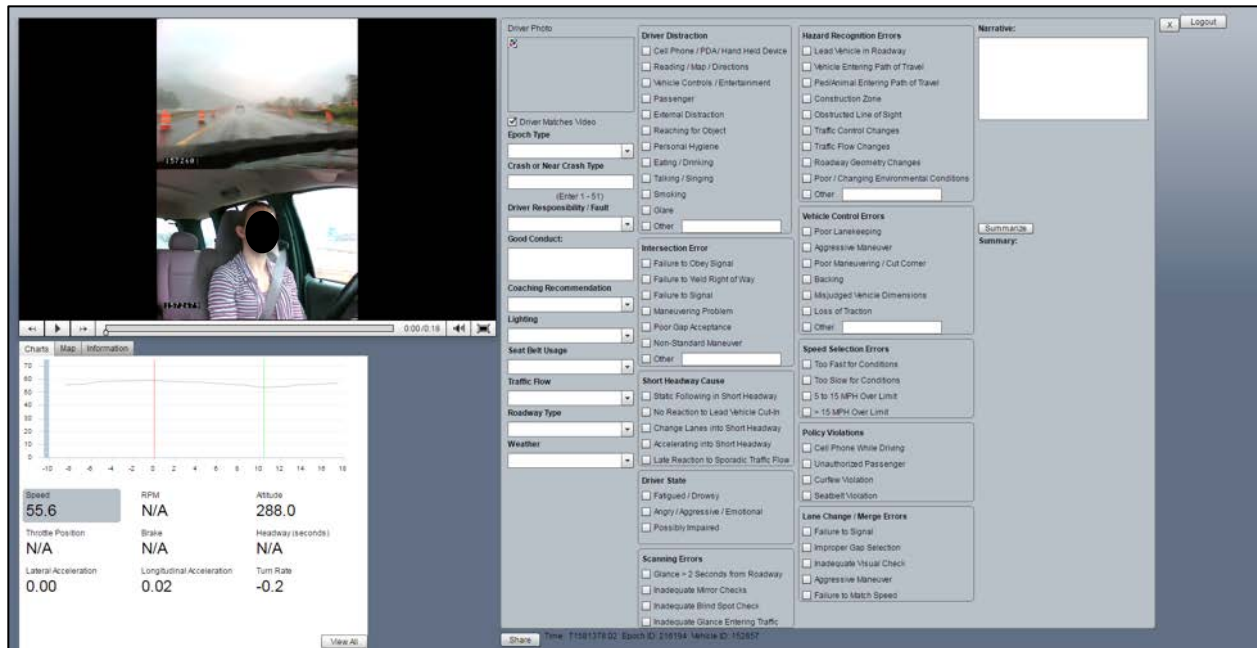


Figure 14. Screenshot. MinDR software tool where coding of each coachable event occurred.

This page allowed the reductionist to record a battery of variables by using drop-down menus. Key information that was recorded for each epoch included time of day, roadway type, weather conditions, seat belt use, etc. The remaining categories concentrated on any observable distractions, intersection errors, short headway conflicts, driver state, scanning errors, hazard recognition errors, vehicle control errors, speed selection errors, potential GDL violations, and lane change/merge errors.

Reductionists determined whether the events should be considered “Coaching Recommended.” Specific Coaching Recommended events were then defined as coachable events and were queued, following reduction manager review and approval, for inclusion on the parent/participant Web page. Such events were chosen because they provided a valuable opportunity to help teen participants identify inappropriate behaviors or improper actions and could be used to provide corrective measures and suggestions to improve driver knowledge and future safety. Events were recommended for coaching to address undesirable/bad behaviors, as well as exemplary/good behaviors and/or reactions.

Coaching notes were written to accompany each error in order to provide justification as to why a specific error was selected and to also give parents and teens suggestions for minimizing the occurrences of these errors.

Inter- and Intra-Rater Reliability

As coding of the video data was largely subjective, an inter- and intra-rater reliability test comprised of 20 randomly selected events was administered to reductionists. This test was given to measure the accuracy among reductionists as a group and to measure individual reductionist

precision to that of a predetermined “gold standard.” This test was administered twice throughout the course of the study: at the midway point of the study and near the study’s conclusion. The results from inter-rater tests indicated that the four trained coders were 86% accurate to the gold standard across the entire reduction. Additionally, the overall intra-rater test combined with QA indicated that trained coders were 89% accurate to the gold standard across the entire reduction.

SURVEYS, QUESTIONNAIRES, AND INTERVIEWS

Potential participants completed initial screening using a survey created by VTTI with LimeSurvey, an open source online survey tool. Participants that met all of the survey’s selection criteria (see section Methods: Participants) were asked to come to VTTI for informed consent and vehicle instrumentation. While the vehicle was being instrumented, participants were thoroughly informed of the study’s purpose, requirements, compensation, and consent forms. Upon providing consent and having their vehicle instrumented, participants were asked to complete a series of LimeSurvey questionnaires. Both parents and teens completed surveys at the following intervals:

- Beginning of study
- Six months into participation
- Upon receipt of licensure
- Three months post-licensure
- Six months post-licensure
- End of study

The final closeout interview was completed seven months after teens had received their independent license, concluding the enrollment period in the study. The closeout interviews were completed on site at VTTI. Parent and teen interviews were conducted concurrently but separately while the instrumentation was being removed from the participants’ vehicles.

The various questionnaires and surveys asked teens about a wide range of topics, including perceived risk, parent trust/knowledge, parent restrictions, friends’ risky behaviors, risky driving prevalence in the general population, estimated exposure, driving knowledge, etc. Likewise, parents were asked about their limits on teen driving, consequences, attitudes toward supervised practice driving, etc. During the final end-of-participation interview, parents and teens were asked their opinions of the MiniDAS real-time alerts and the feedback Web page.

DATA QUALITY ASSURANCE AND QUALITY CONTROLS

DCS data were subjected to numerous stringent quality assurance/quality control (QA/QC) measures. Table 5 outlines the QA/QC checks practiced throughout the course of the DCS during the data collection.

Table 5. QA/QC measures.

QA/QC Concern	Method
<i>Vehicle Communication</i>	Several diagnostic queries were run on a weekly basis to check vehicle cellular connectivity and communication in addition to health-check upload status and disk capacity remaining. These queries also helped to determine if the unit was not operational due to a power-related or other technical issue.
<i>Continuous Trip Files</i>	Upon completion of an SD card swap, all continuous trip files were loaded into the database. A sample of three files were randomly selected from the SD card: one each from near the beginning, middle, and end of the card collection period. These files were then reviewed and coded by a reductionist. The reductionist checked the following items: video camera views, audio quality, epoch captures, GPS variables, power warning flags, vehicle network status, accelerometer values, and lane tracking probabilities. Project personnel were notified if there were issues present with any vehicle.
<i>Epochs</i>	Given the requirement to upload the epochs to the feedback website, all epochs which were uploaded via cellular network underwent rapid reduction where trained data coders reviewed them and, if found to be appropriate for coaching, they underwent further review by the reduction manager before being uploaded to the participant website.

CHAPTER 3. RESULTS

Statistical and/or descriptive analyses were conducted on the six research objectives, and those results are presented in the subsequent sections. Data were collected on 92 novice drivers. Eighty-nine novice drivers received their independent driving licenses and had data collected during their independent driving phase. After the teens received their provisional license, data were typically collected for seven months total: six months of data collection included real-time and post hoc feedback to the novice drivers; the last month (seventh month) did not provide any feedback (Figure 15).

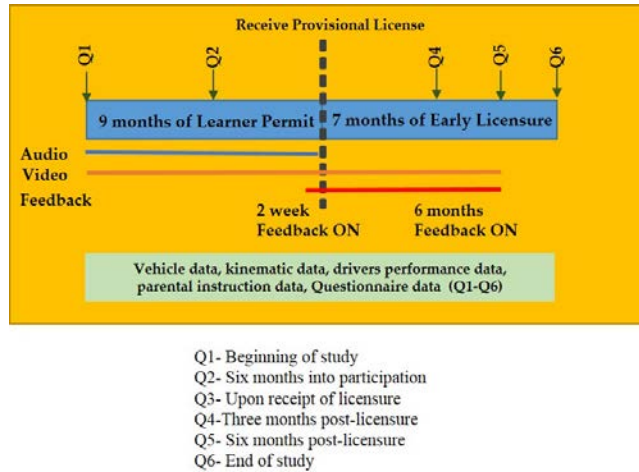


Figure 15. Diagram. Timeline of the DCS data collection period.

Given the importance of parental oversight, the data will be presented comparing teenagers whose parents logged in to the website at least one time during the course of the study versus those teens whose parents never logged in (Table 6). Fifty-eight percent of parents logged in to the website at least one time.

Table 6. Number of teen drivers by gender and by parental login status.

Login Status	Female	Male	Grand Total
No Parent Login	21	17	38
Parent Login	25	29	54
Grand Total	46	46	92

Additionally, we conducted baseline analysis of teenage crash rates in the state of Virginia using the crash data from the Virginia Department of Transportation (VDOT) and licensed teenage driver’s data from the DMV for the years 2010–2014. Please see Appendix A for these results.

The following results section will be organized by the research objectives, as stated in the introduction. Several measures of driving performance were analyzed to assess the impact of the DCS on teen driving such as CNC, coachable events, and elevated g-force events.

OBJECTIVE 1

Do real-time and post hoc feedback reduce rates of CNC, elevated g-force events, and coachable events involvement for teen drivers as compared to a control group not receiving such feedback?

In order to assess the impact of feedback on teen driving performance, we analyzed CNC rates, elevated g-force events, and coachable event rates under this objective. Additionally, in order to understand the role of parental involvement, we included parental website login activity as a variable in the following analyses.

CNC Rates

CNC rates were calculated based upon whether the parents of the teenage drivers logged in to the website to observe the post hoc feedback as compared with the control group of teenagers who did not receive feedback (SPDS). A Poisson random intercept regression model analysis indicated that teenagers whose parents monitored the website had a significantly lower CNC rate ($p < 0.05$) than the SPDS teenagers. Teenagers whose parents monitored the website also had significantly lower CNC rates as compared with the DCS teenagers whose parents did not monitor the website (Figure 16). Teenagers whose parents did not monitor the website did not have significantly different CNC rates than the SPDS teen drivers. There was also no effect of time (Table 7).

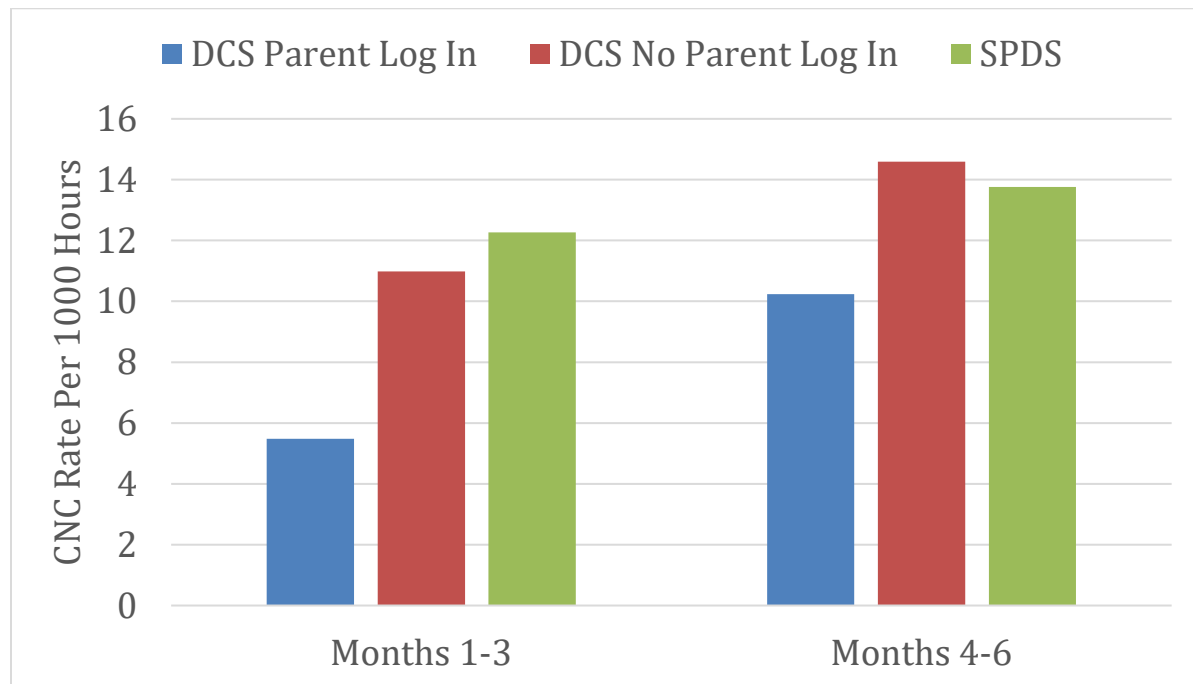


Figure 16. Graph. CNC rate for DCS teens whose parents monitored the website, those DCS teens whose parents did not monitor the website, and SPDS teens (no feedback).

Table 7. Contrast estimate results. Poisson random intercept regression model results.

Label	Mean Estimate	Mean Confidence Limits	Mean Confidence Limits	L'Beta Estimate	Standard Error	Alpha	L'Beta Confidence Limits	L'Beta Confidence Limits	Chi-Square	Pr > ChiSq
DCS Parent Login vs. SPDS	0.6095	0.3991	0.9311	-0.495	0.2161	0.05	-0.9186	-0.0714	5.25	0.022
Exp (DCS Parent Login vs. SPDS)				0.6095	0.1317	0.05	0.3991	0.9311		
DCS No Parent Login vs. SPDS	0.9825	0.6406	1.5069	-0.0176	0.2182	0.05	-0.4453	0.4101	0.01	0.9356
Exp (DCS No Parent Login vs. SPDS)				0.9825	0.2144	0.05	0.6406	1.5069		
DCS Parent Login vs. DCS Parent No Login	0.6204	0.3725	1.0332	-0.4774	0.2603	0.05	-0.9875	0.0327	3.36	0.066
Exp (DCS Parent Log in vs. DCS No Parent Login)				0.6204	0.1615	0.05	0.3725	1.0332		
Time (Months 1-3 vs. Months 4-6)	0.771	0.5477	1.0853	-0.2601	0.1744	0.05	-0.602	0.0818	2.22	0.136
Exp (Months 1-3 vs. Months 4-6)				0.771	0.1345	0.05	0.5477	1.0853		

Figure 17 presents the percentage of participants who were involved in zero CNC events, one to three CNC events, and four or more CNC events. This figure indicates that the DCS, regardless of whether parents monitored the website or not, had a higher percentage of participants who were not involved in any CNC events compared with the teens who did not receive any feedback. DCS teens whose parents did not monitor the website also had the highest percentage of teenagers who were involved in four or more CNC events.

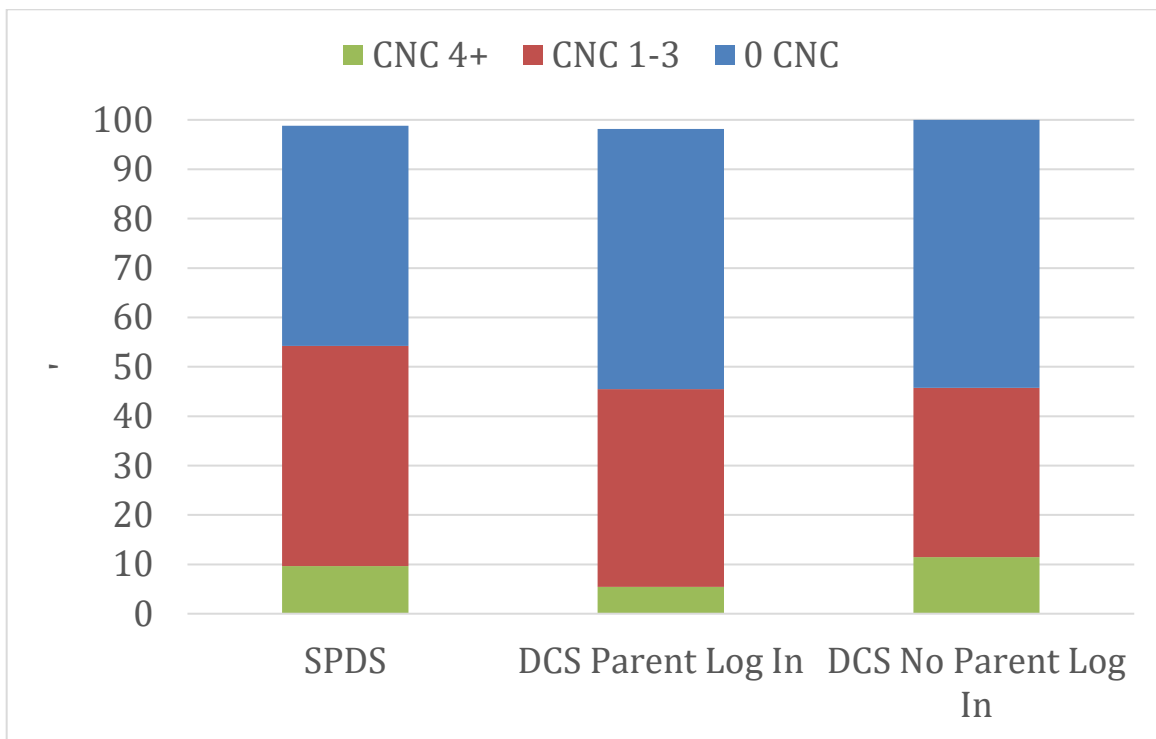


Figure 17. Graph. Percentage of participants that were involved in 0 CNC events, 1 to 3 CNC events, and 4+ CNC events.

Coachable Events

An analysis was also conducted on coachable events. Coachable events are events where (1) the teen driver exceeded a vehicle kinematic threshold (e.g., braked above -0.55 g), and (2) a review by trained coders determined the event to be valid for providing feedback to the teen driver and parent (refer to Figure 5 for diagram of epoch processing). Figure 18 shows the coachable event rates for teens whose parents monitored the website and the teens whose parents did not monitor the website. Teens whose parents monitored the website had lower overall coachable event rates, which decreased over time. Teens whose parents did not monitor the website had higher coachable event rates with only a modest decrease over time (Table 8).

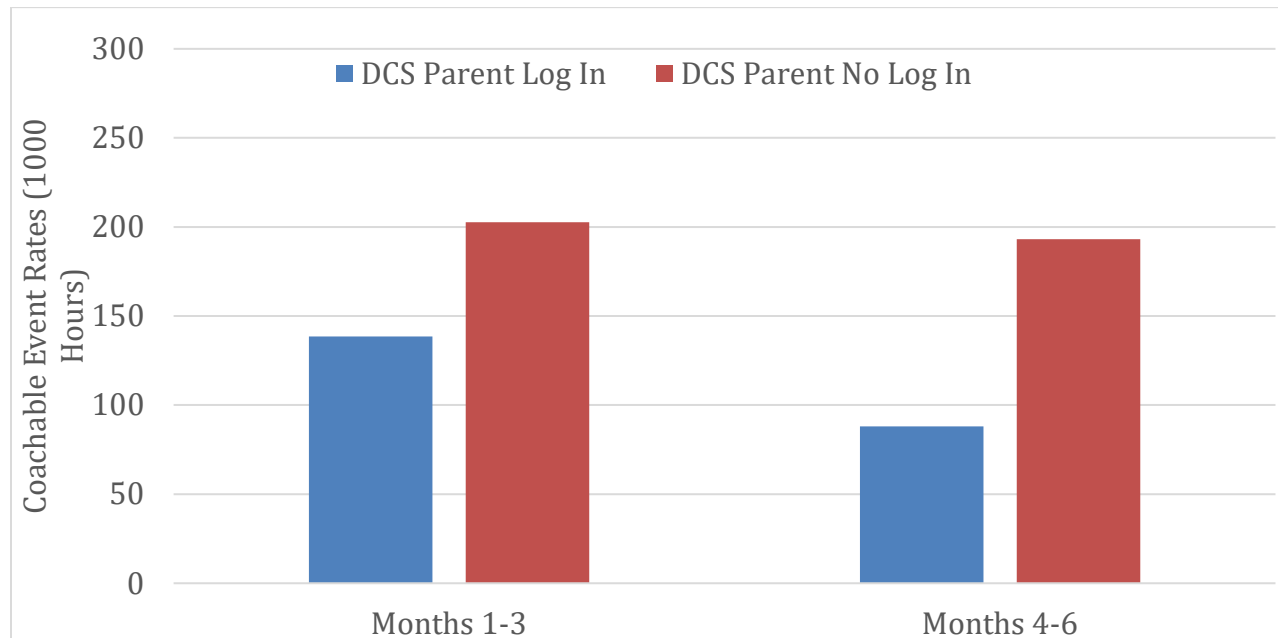


Figure 18. Graph. Coachable event rates for teens whose parents’ monitored website versus those whose parents did not monitor website.

Table 8. Contrast estimate results. Poisson regression results for coachable event analysis.

	Mean Estimate	Mean Confidence Limits	Mean Confidence Limits	L’Beta Estimate	Standard Error	Alpha	L’Beta Confidence Limits	L’Beta Confidence Limits	Chi-Square	Pr>ChiSq
DCS Parent Login vs. DCS No Parent Login	0.5739	0.3823	0.8616	-0.5552	0.2073	0.05	-0.9615	-0.149	7.18	0.0074
Exp (DCS Parent Login vs. DCS No Parent Login)				0.5739	0.119	0.05	0.3823	0.8616		
Months 1-3 vs. Months 4-6	0.7202	0.4315	1.202	-0.3283	0.2614	0.05	-0.8405	0.1839	1.58	0.2091
Exp (Months 1-3 vs. Months 4.6)				0.7202	0.1882	0.05	0.4315	1.202		

The final analysis conducted for this research objective was to compare the elevated g-force event rates from DCS to SPDS to see if feedback improved the elevated g-force event rates for longitudinal deceleration, longitudinal acceleration, and lateral acceleration. The frequencies of elevated g-force events were calculated in both studies using the thresholds shown in Table 5 regardless of whether a “coachable” event resulted or not. The analysis was conducted in this

way because none of the events at these thresholds were coded and/or validated for the SPDS study. Thus, this provided the only way to compare the two studies fairly. The results indicated no significant differences between the two studies, DCS teens whose parents monitored the website, DCS teens whose parents did not monitor the website, and SPDS teens (Figure 19).

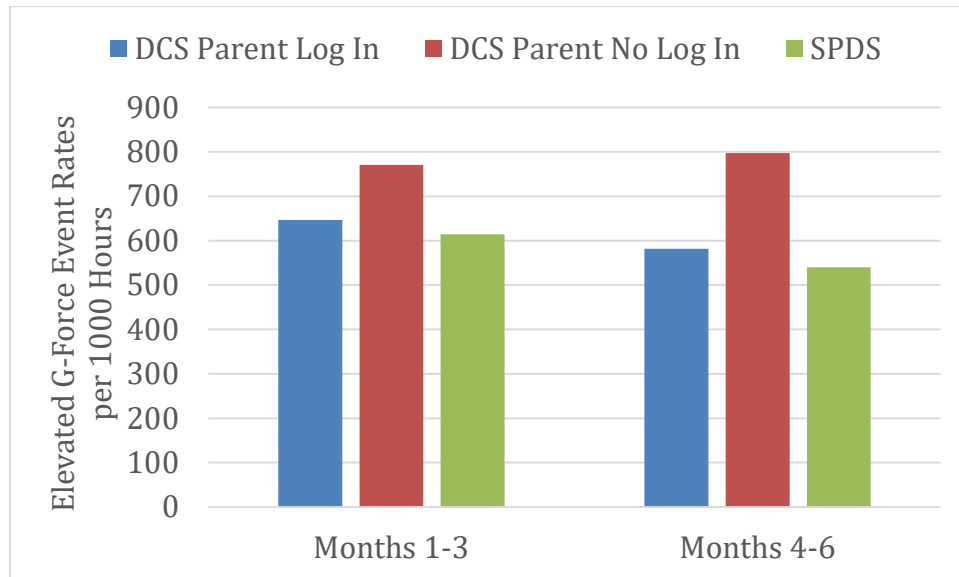


Figure 19. Graph. Elevated g-force event rates for DCS teens whose parents logged in to website, those teens whose parents did not log in to website, and the SPDS teens (no feedback).

A Pearson correlation was calculated to assess the relationship between CNC events and elevated g-force events. This analysis indicated a correlation coefficient of 0.43, $p < .05$. A second Pearson correlation was conducted to assess the relationship between elevated g-force events and coachable events. This correlation was stronger at 0.68, $p < .05$.

OBJECTIVE 2

Objective 2: What are the time trends of each type of coachable event and how did parental involvement influence this behavior?

Figure 19 shows occurrences of four of the coachable event types across the first six months of driving: hard braking, hard cornering, fast start, and exceeding speed. The results shown here indicate that real-time and post hoc feedback resulted in reductions in hard braking and hard cornering events, but did not appear to reduce the rates of fast starts or exceeding speed over time.

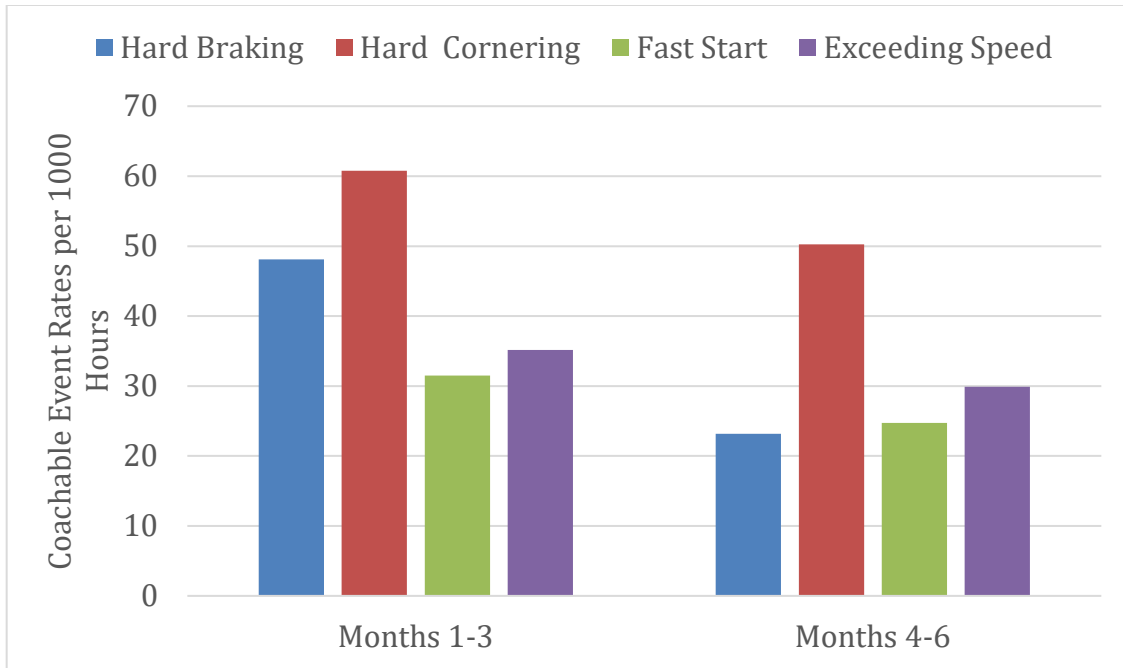


Figure 19. Graph. Coachable event rates for four feedback types: hard braking, hard cornering, fast start, and exceeding speed across the first 6 months of driving.

Coachable event rates were also evaluated for teenagers with parents who logged in to the website versus those whose parents did not log in. Analyses indicate that there was an overall reduction in the number of coachable events for teens whose parents logged in versus those who did not. Additionally, there was a reduction in coachable event rates for hard braking and hard cornering events among both teens whose parents were reviewing coachable events and those whose parents were not reviewing events. Results are shown in Figure 20 and Figure 21. It is possible that the teenagers with parents who were not monitoring also reduced their rates of coachable event occurrence simply because they were annoyed by the auditory alert that was presented when a kinematic threshold was exceeded.

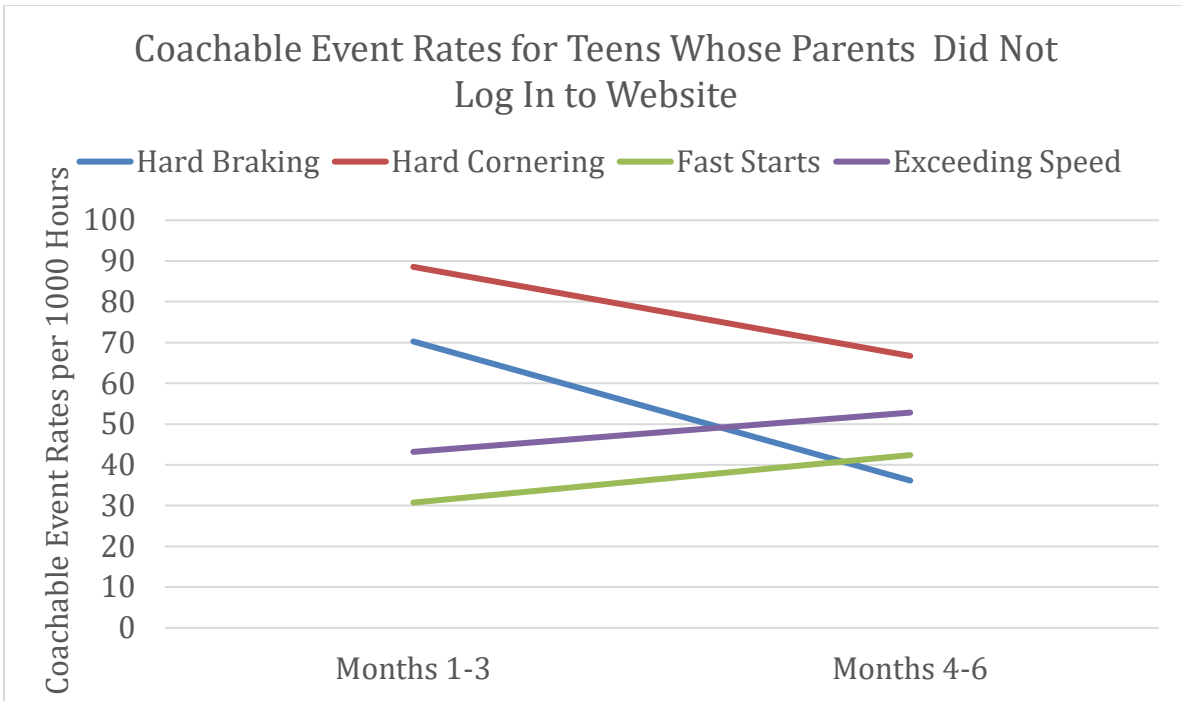


Figure 20. Graph. Coachable events by trigger type for teens of parents who never logged in to website.

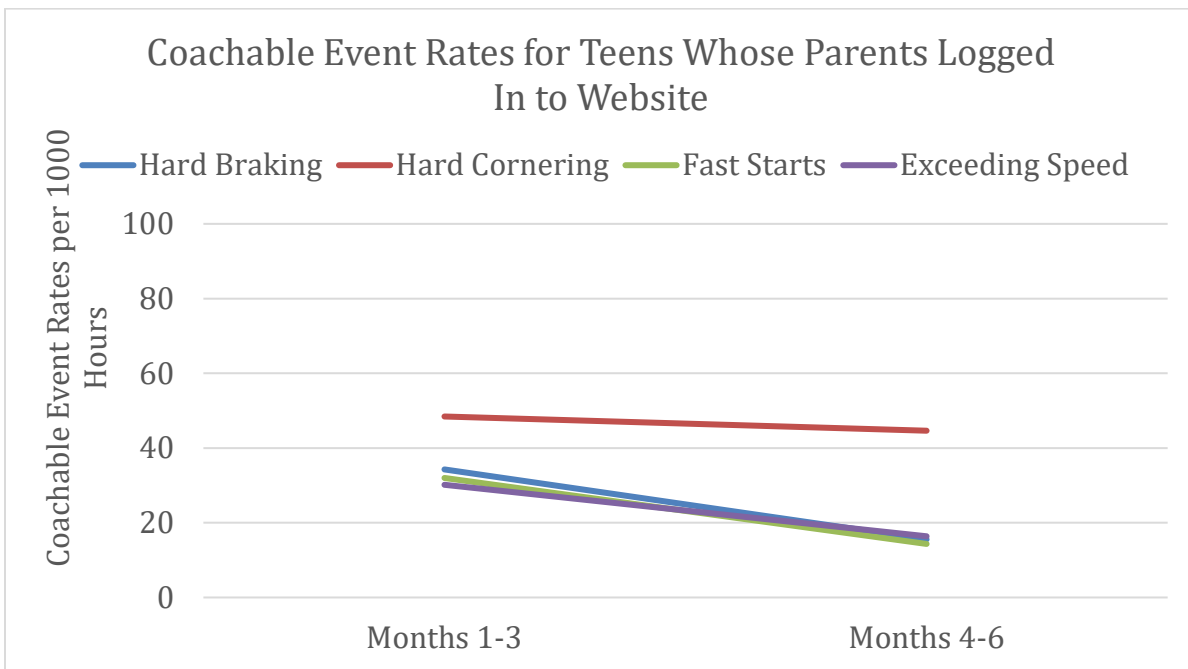


Figure 21. Graph. Coachable events by trigger type for teens of parents who logged in to website.

Figure 22 shows the rate of lane departure events across the months since licensure. This coachable event type was nearly three times more frequent than any other event type; however,

its association with CNC rates is unknown. Again, the teenagers whose parents were not reviewing the website showed a modest decline in lane departure warnings over the first six months of driving. The teenagers with parents who logged in to the website saw increases in lane departure warnings over time. This spike may be caused by general habituation.

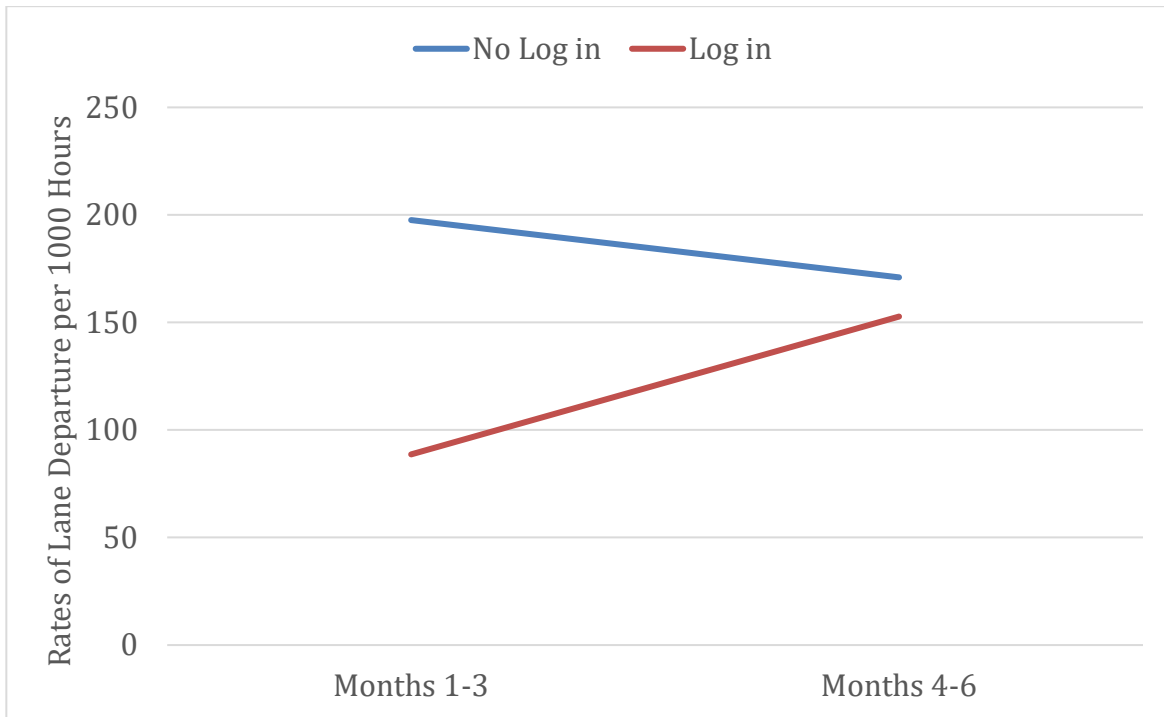


Figure 22. Graph. Lane departure warning over months since licensure by teenagers whose parents logged in to website versus teenagers whose parents did not log in to website.

OBJECTIVE 3

Are there any observable unintended consequences for the teens who received feedback versus the teens who did not receive feedback?

Figure 21 and Figure 22 from the previous research question all show a general decrease in the rates of coachable events occurring during the feedback phase. The exceptions to this are an increase in lane departures in Months 4–6 for the teens whose parents monitored their performance, as well as an increase in speeding and fast starts in Months 4–6 for teens with no parental monitoring. These increases over time may suggest that these triggers were less effective than the other trigger types. This lack of effectiveness could result from a lack of understanding of this trigger’s importance or an attitude shift in the teens whose parents were not monitoring their driving.

In Figure 22, there is an interesting pattern regarding lane departure triggers showing that teens whose parents were monitoring them, while still experiencing lower lane departure triggers than the teens whose parents were not monitoring, exhibited an increase in these triggers during Months 4–6. This could be an indication that the teenagers were not responding to this lane departure alert appropriately. Many participants, teens and parents, argued (with VTTI) that the

trigger was set to be too sensitive and, thus, they did not heed its warnings. Other teenagers reported that while it was annoying, it helped them remember to use their turn signal. Given these mixed results, more research is needed on the design and use of this type of feedback.

OBJECTIVE 4

After the feedback was turned off, did the occurrence of CNC and coachable events increase?

For the last month of data collection (seven months post licensure), the feedback component of the MiniDAS was turned off to assess how teenagers' driving performance changed without real-time feedback present. The underlying question is whether six months of driving with feedback taught the teenagers the types of behaviors that are unsafe and whether six months of driving in this manner had also produced *habitually* safe driving behaviors. To answer this research question, we analyzed CNC rates and coachable event rates, and, in order to understand the role of parents we included parents' website login data in this analysis.

Figure 23 shows the rate of CNC events over the first seven months for the DCS monitoring and no monitoring groups. The results indicate that CNC rates were relatively lower when feedback was present; however, once feedback was turned off, the teenagers' CNC rates went up. The Poisson regression analysis suggested that CNC rates for Months 1–6 six were significantly different from Month 7 ($\beta = -0.76, p < 0.05$) (Table 9).

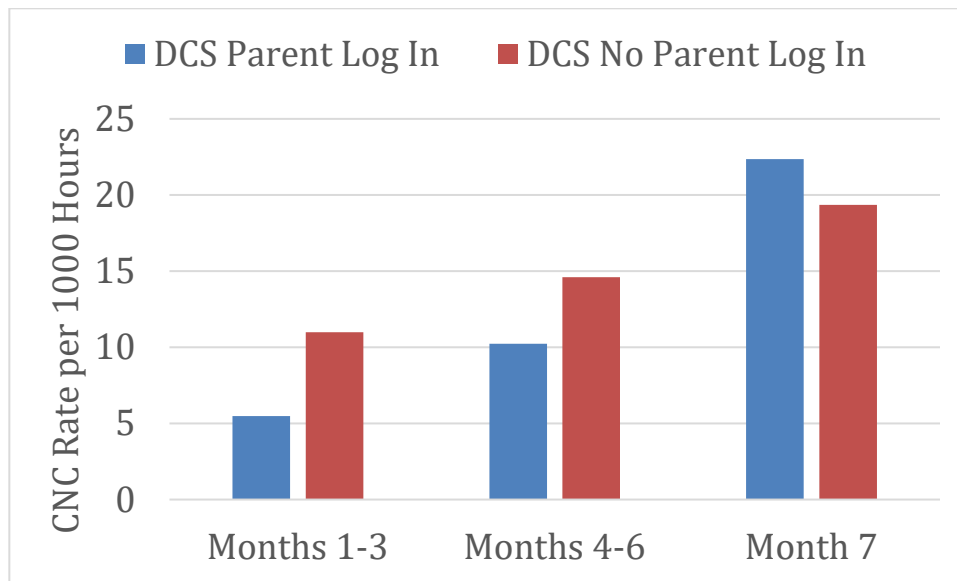


Figure 23. Graph. CNC rates for teens whose parents monitored website versus those teens whose parents did not monitor website.

Table 9. Contrast estimate results. Poisson regression results for coachable event analysis.

	Mean Estimate	Mean Confidence Limits	Mean Confidence Limits	L'Beta Estimate	Standard Error	Alpha	L'Beta Confidence Limits	L'Beta Confidence Limits	Chi-Square	Pr > Chi Square
DCS Parent Login vs. DCS Parent No Login	0.7338	0.4065	1.3245	-0.3096	0.3013	0.05	-0.9002	0.281	1.06	0.3042
Exp (DCS Parent Login vs. DCS Parent No Login)				0.7338	0.2211	0.05	0.4065	1.3245		
Months 1-6 vs. Month 7	0.4685	0.2414	0.9092	-0.7583	0.3383	0.05	-1.4213	-0.0952	5.02	0.025
Exp (Months 1-6 vs. Month 7)				0.4685	0.1585	0.05	0.2414	0.9092		

Figure 24 shows the coachable events for the teen driver whose parents logged in to the website versus those who did not. While there appears to be an increase in coachable event rates for Month 7, no significance differences were found for coachable event rates for Months 1–6 versus Month 7.

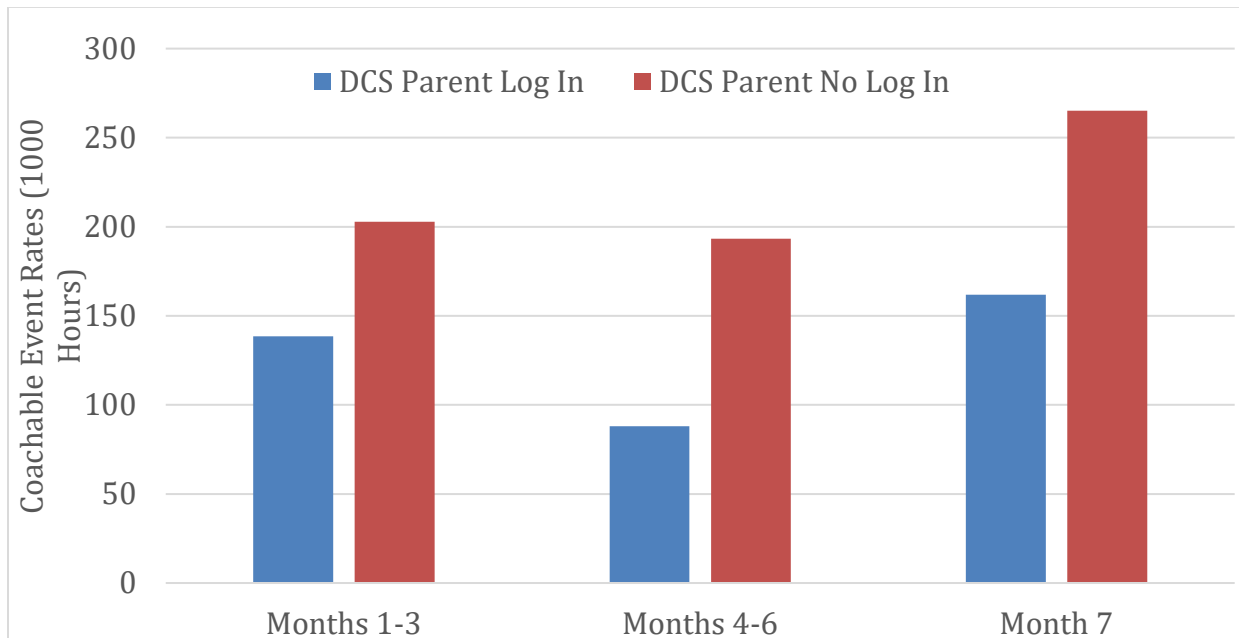


Figure 24. Graph. Coachable event rates for teen drivers whose parents logged in to website and those who did not log in to website.

A Pearson correlation was conducted to assess the relationship between CNC rates and coachable events. The Pearson *R* correlation coefficient was statistically significant with a correlation coefficient of $R = 0.29$ ($p = .006$). A correlation of 0.29 is considered to be a moderate correlation when measuring human behavior.

Figure 25 and Figure 26 show the coachable event rates by trigger type for teenagers with parents who did not log in to the website and those parents who did across the first six months (with feedback) and the seventh month (without feedback). Generally, there was an increase in coachable event rates for Month 7 for all teen drivers. The rates for the teens whose parents were

monitoring were still generally lower than those of the teens whose parents did not monitor, even in Month 7.

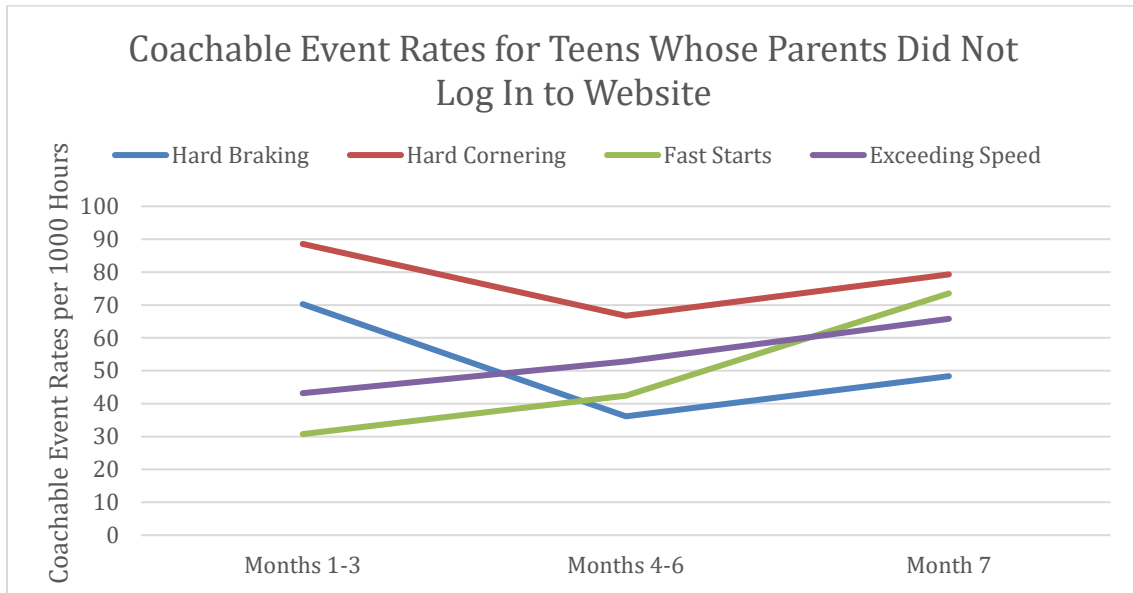


Figure 25. Graph. Coachable event rates by trigger type for teenagers with parents who did not log in to website.

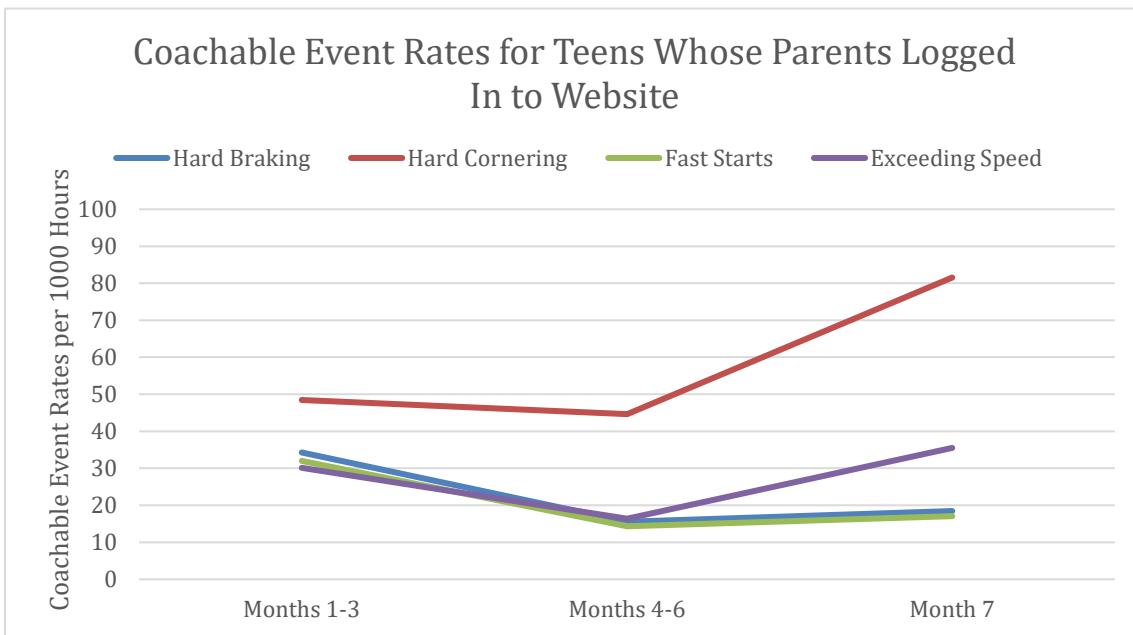


Figure 26. Graph. Coachable event rates by trigger type for teenagers with parents who logged in to website.

OBJECTIVE 5

What does driving performance feedback indicate to be the greatest behavioral error for teens? How often do they engage in these erroneous behaviors?

This analysis assessed whether the occurrence of behavioral errors improved with real-time and post hoc feedback. Driver errors include behaviors that may contribute to the occurrence of a coachable event, such as poor vehicle control, poor speed selection, secondary task engagement, and drowsiness. The frequency of occurrence where driver errors were associated with the event was assessed to determine if teenagers were observed making fewer driver errors, as associated with these coachable events, over time.

In Figure 27, the rates of driver errors for Months 1–3, Months 4–6, and Month 7 are shown broken down by rate of driver errors and parental monitoring. The results indicate that the rate of errors was lower for the teenagers whose parents monitored their driving for Months 1–6. Once feedback and monitoring were turned off for teens and parents, the rate of errors increased for all teenage drivers but more dramatically for the teens whose parents did not monitor the website.

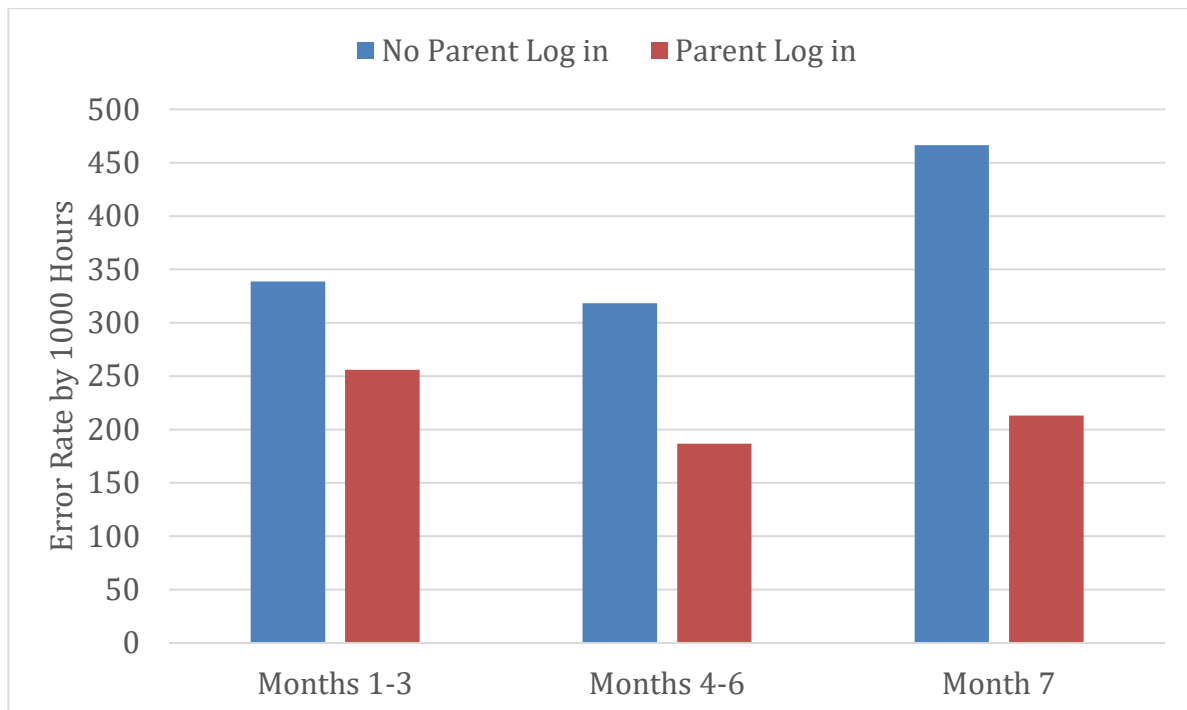


Figure 27. Graph. Rate of driver errors for teens by parental monitoring versus no parental monitoring.

Figure 28 and Figure 29 show the rate of errors by type for teens whose parents monitored their behavior and teens whose parents did not monitor their behavior. The most frequent types of errors are similar for both groups, and include vehicle control, speed selection, hazard recognition, and distraction. Again, overall error rates were higher for those teens whose parents were not monitoring the coaching website, and their performance had only modest improvements. Error rates for teens whose parents monitored the coaching website appeared to

decrease over time, whereas those teens whose parents did not monitor the coaching website remained relatively flat over time. Error rates increased after feedback was turned off in Month 7 for both groups of teen drivers.

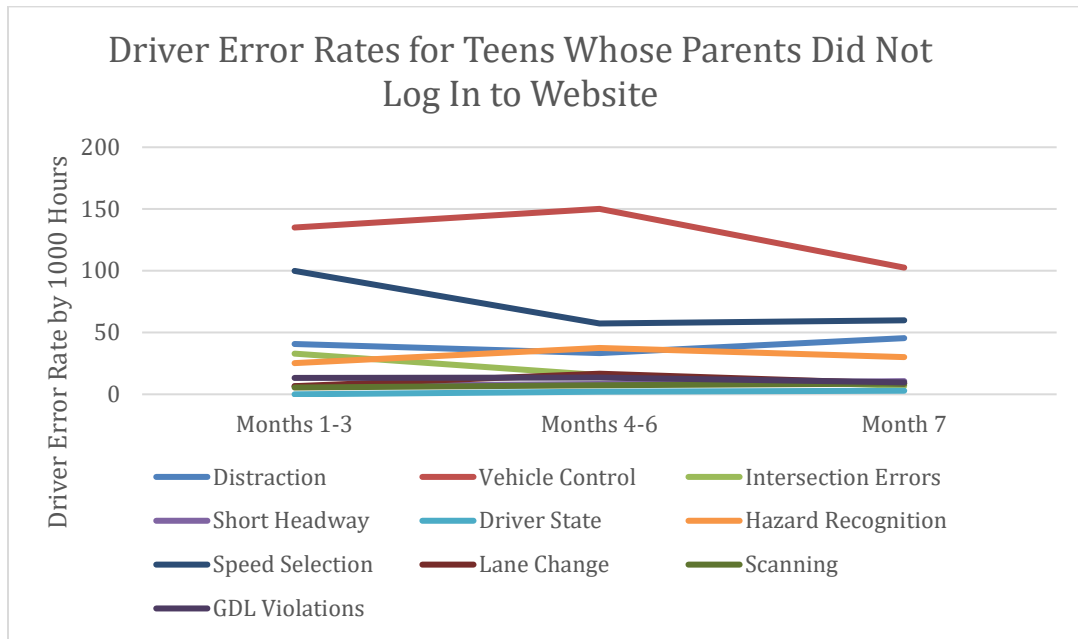


Figure 28. Graph. Rate of errors by type for teens with no parental monitoring.

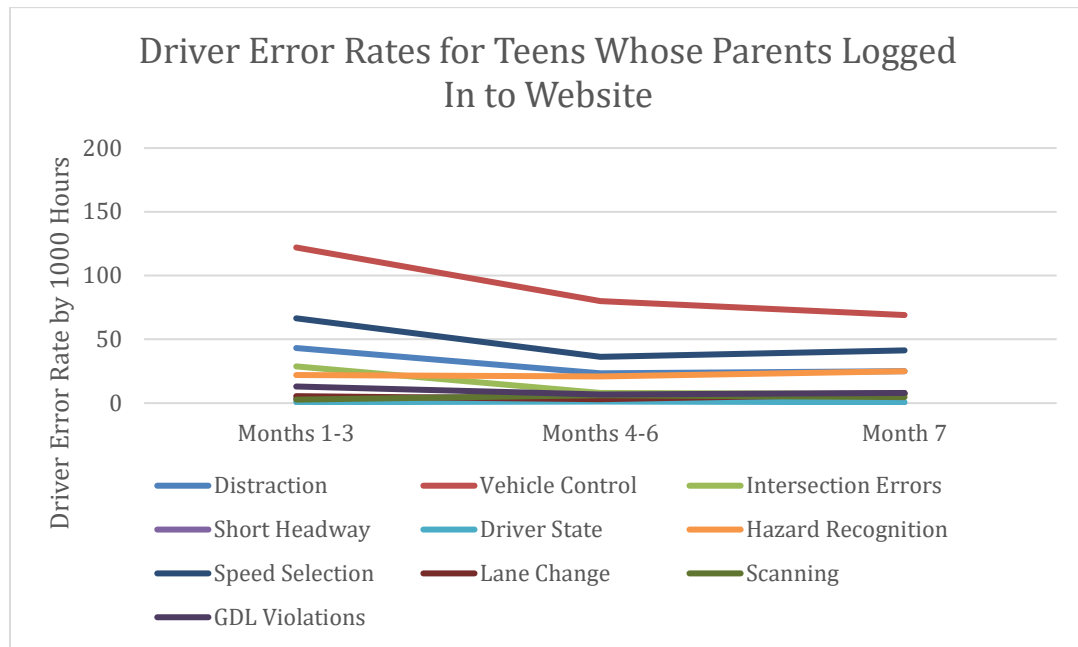


Figure 29. Graph. Rate of errors by type for teens with parental monitoring.

To better understand the types of behaviors occurring for the top four most frequent errors, Figure 30 and Figure 31 are shown below. For vehicle control (no figure), the most prevalent

type of error was aggressive driving maneuvers (over 99%). For speed selection (Figure 32), the errors are broken out by Too Fast for Conditions (environmental and weather conditions), Over the Speed Limit (by at least 5 mph), and Reckless Driving (more than 15 mph over the speed limit).

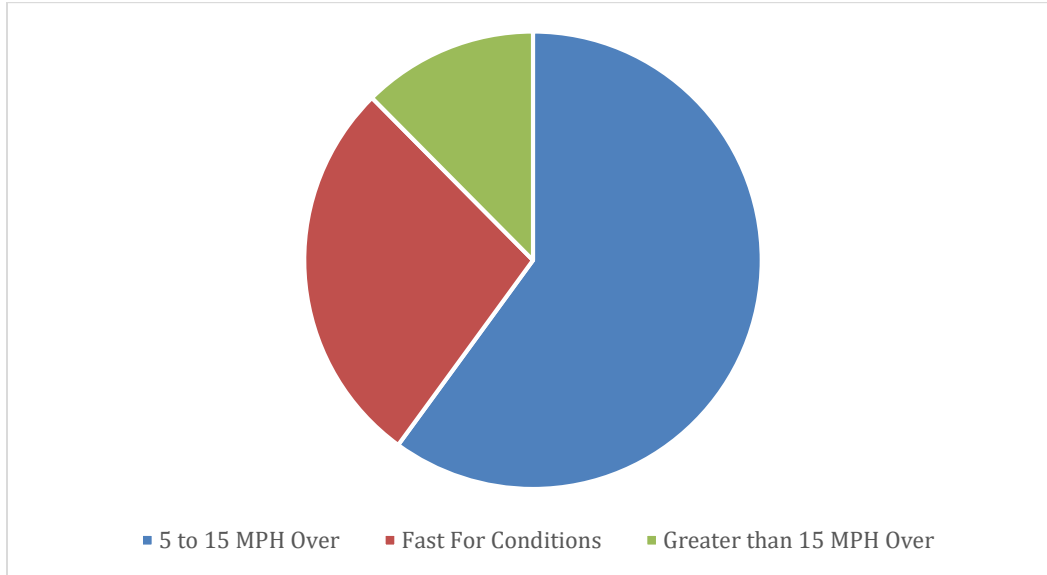


Figure 30. Graph. Types of behavior occurring for speed selection errors.

Many different types of distraction caused distraction errors resulting in coachable events (Figure 29). The two most frequent errors were talking on and interacting with a cell phone, followed by talking and interacting with passengers.

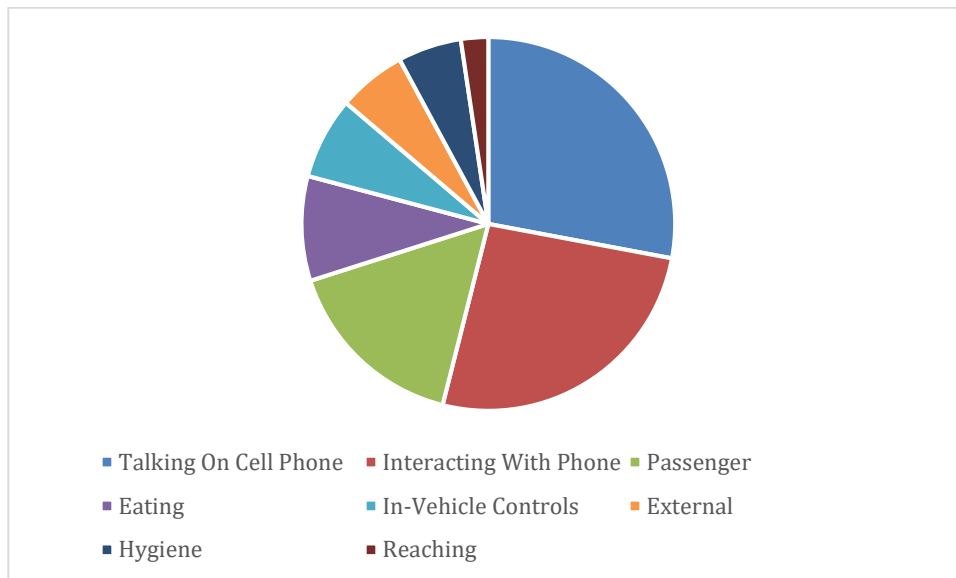


Figure 31. Graph. Types of distractions occurring for distraction errors.

Hazard perception was the fourth most frequent error. The types of hazard perception errors that were most frequent among these teenagers were traffic control device, lead vehicle interaction, and inconsistent traffic flow, which comprised over 75% of the hazard perception errors observed. An illustration of these and other hazard perception errors is provided in Figure 32.

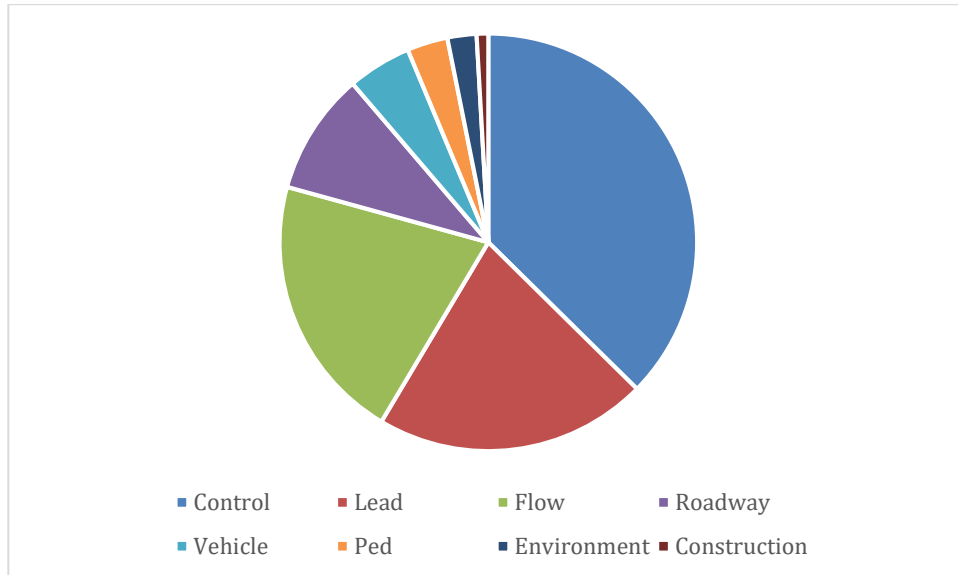


Figure 32. Graph. Types of hazards occurring for hazard perception errors.

Figure 33 shows the frequency of GDL violations. These are only those violations that were observed as part of the occurrence of a crash, near-crash, or coachable event. As shown, cell phone use was a frequent occurrence throughout the first seven months of licensure. Carrying too many teenage passengers stayed steady over time as well. Seat belt non-use appears to have gone down over time, while curfew violations were infrequent and occurred toward the end of the first seven months of driving.

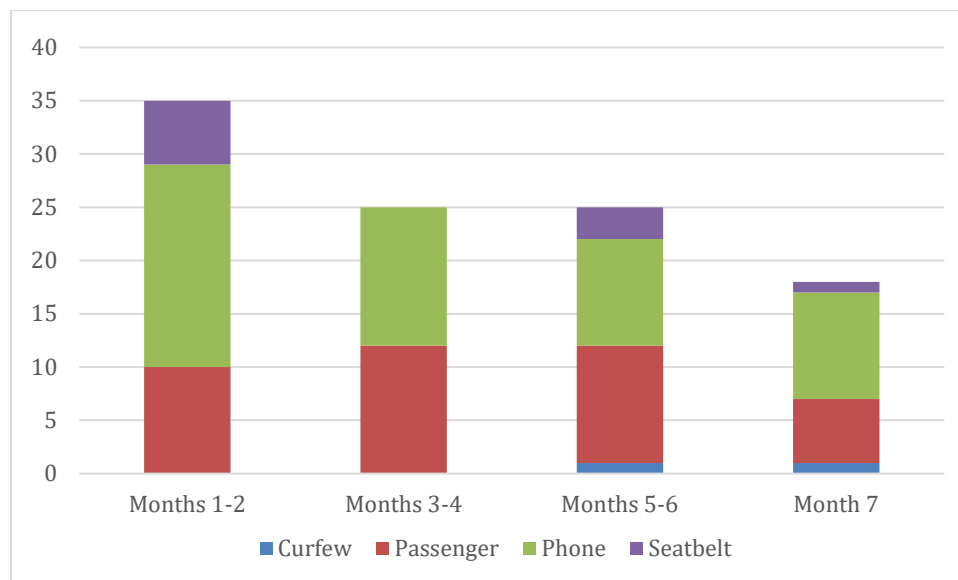


Figure 33. Graph. GDL violations over time.

OBJECTIVE 6

What are parents and teenager's opinions and attitudes towards the Driver Coach System after using it for 6 months?

The following analysis will present the parents' responses followed by the teenage participants' responses.

Figure 34 shows the percentage of parents responding with their level of agreement to the statement, "I would recommend DCS to my friends." Most parents responded that they either strongly or moderately agreed that they would recommend the DCS system to their friends.

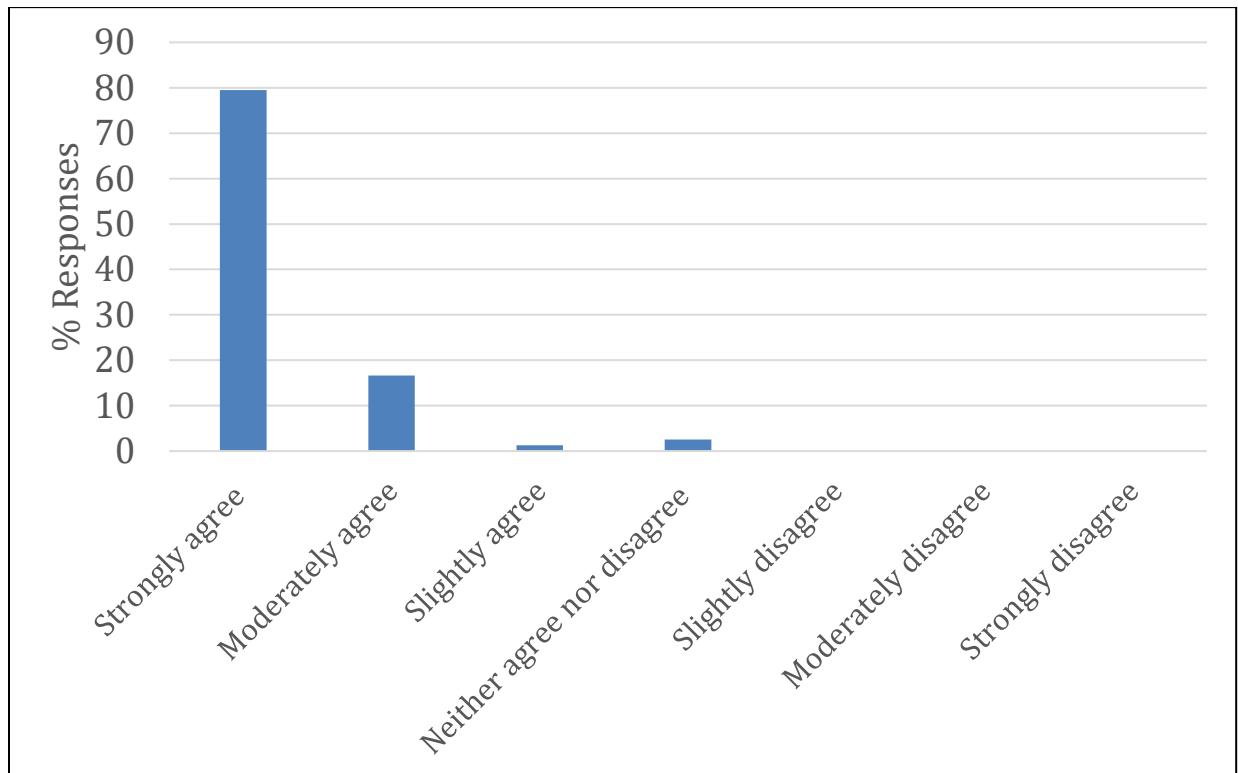


Figure 34. Graph. Parental agreement (percentage of responses) with the statement, "I would recommend DCS to my friends."

Figure 35 shows the percentage of parents responding with their level of agreement to the statement, "My teenager drives more safely now than if he/she had not participated in the study." Most parents indicate that they felt the DCS system helped their teen drive more safely.

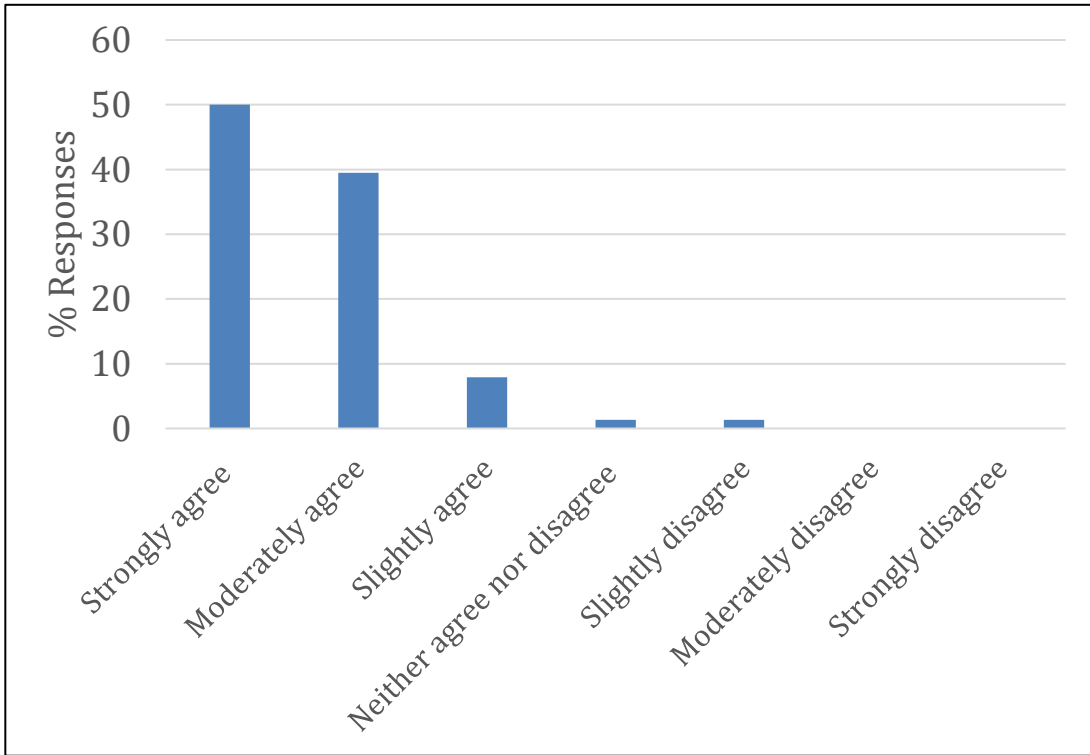


Figure 35. Graph. Parental agreement (percentage of responses) with the statement, “I believe my teen drives more safely than if he/she had not participated in the study.”

Figure 36 shows the percentage of parents responding with their level of agreement to the statement, “DCS has helped me teach my teen to drive more safely.” Again, most parents responded positively that DCS did assist them in teaching their teen to drive more safely.

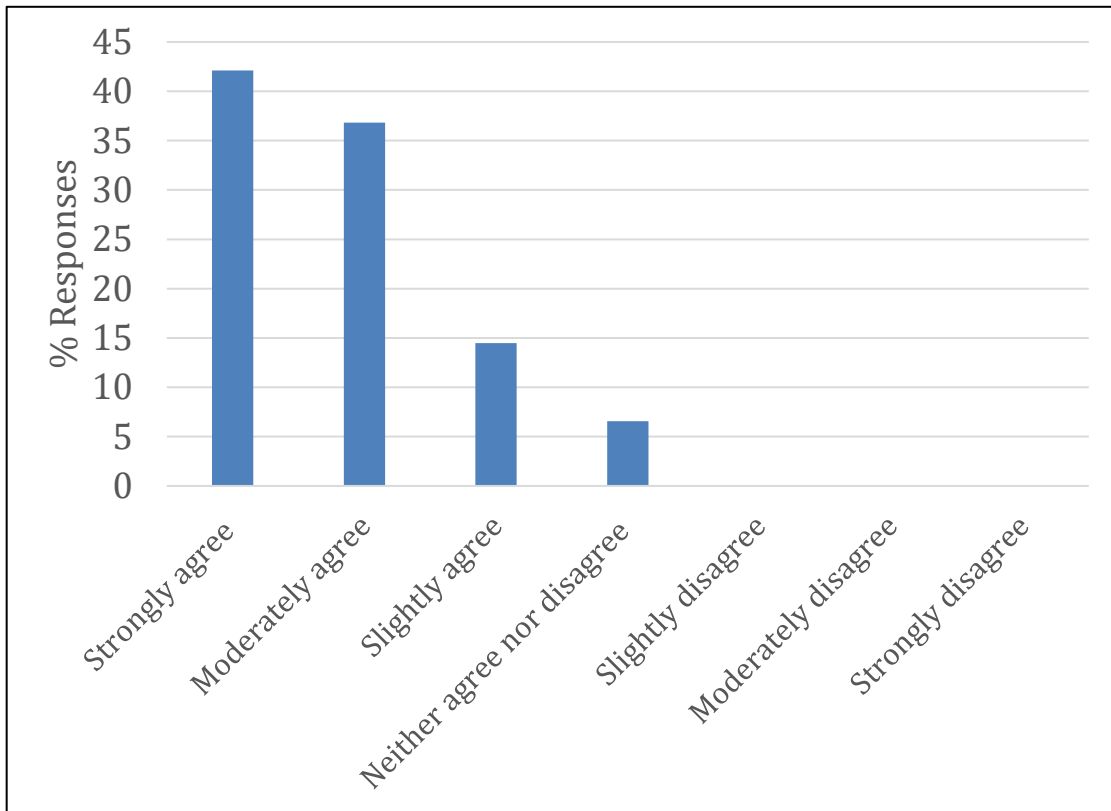


Figure 36. Graph. Parental agreement (percentage of responses) with the statement, “DCS has helped me teach my teen to drive more safely.”

The teenager’s responses to similar statements were not quite as positive as the parents’ responses but remained more positive than negative. Figure 39 shows the percentage of teenagers who responded with their level of agreement to the statement, “I would recommend the DCS system to my friends.”

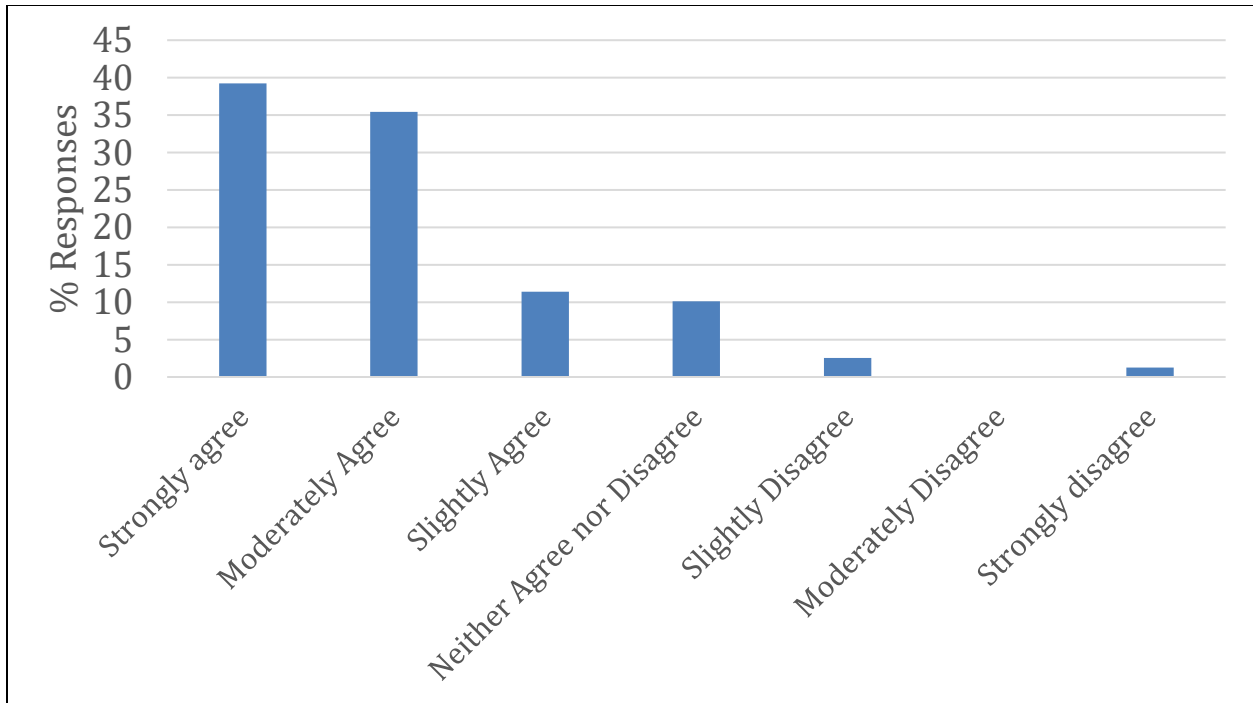


Figure 37. Graph. Teen agreement (percentage of responses) with the statement, “I would recommend the DCS to my friends.”

Figure 38 shows teenage participants’ agreement with the statement, “I drive more safely now, than I would have, if I had not participated in this study.” A majority of the teenagers felt that they did drive more safely now than they would have if they had not participated in the study. Only 20% of the teenage participants were either neutral or responded negatively to this statement.

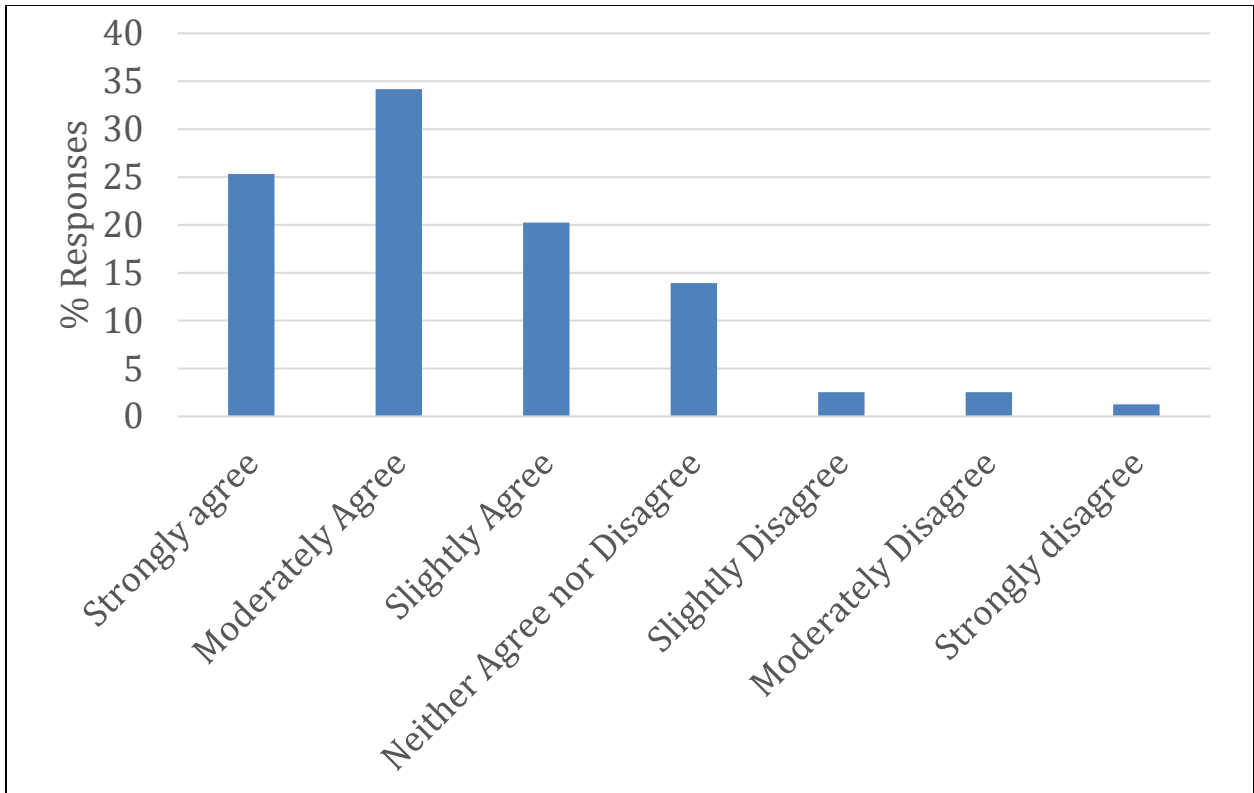


Figure 38. Graph. Teen agreement (percentage of responses) with the statement, “I drive more safely now, than I would have, if I had not participated in this study.”

CHAPTER 4. DISCUSSION

The results of these analyses suggest that the role of parental involvement in the first seven months of independent driving for teenagers led to improved CNC rates, coachable event rates, and even a reduction in errors that lead to the coachable events. The definition of parental involvement that was applied is relatively simple: a parent logged in to the coaching website at least one time during the six-month feedback phase. This very basic definition resulted in significant differences being found in nearly every metric tested.

CNC rates and coachable event rates went up significantly in Month 7 after feedback was turned off. This suggests several things. First, six months is not enough time to provide feedback to instill habitually safe driving habits. Second, it further suggests that parental monitoring of any kind is critical for longer than the supervised practice driving phase, longer than the first seven months of driving, and potentially until teenagers have achieved safe driving habits. Further research is needed to assess at what point safe driving habits have been securely formed in novice teen drivers.

Coachable event rates decreased over time, especially for those teens whose parents monitored the coaching website. This was true primarily for hard cornering and hard braking. Exceeding speed and fast starts increased over time for the teens whose parents did not monitor the website. There was a statistically significant correlation between coachable events and CNC rates, which suggests that these metrics are associated with each other on an individual level. However, the fact that CNCs did not go down over time in this study or in the SPDS study is probably indicative of high individual variability and not general trends in the data. Analyses looking at kinematic risky driving rates and CNC rates in a separate novice teenage driving study have indicated that hard braking, hard cornering, fast start, and exceeding speed events are predictive of CNC occurrence.⁽¹³⁾ Lane departures have not been used in analyses like this prior to the writing of this report; thus, it is unknown what the relationship of lane departures is to CNC rates. Further in-depth analyses will be required to fully understand this relationship between lane departures and CNC rates, but initial analyses suggest that coachable events may only be part of the problem regarding CNC occurrence. Coachable events are probably more indicative of driver errors, whereas CNCs are indicative of multiple errors and contributing factors occurring simultaneously. Due to mismatch between trends in CNC and coachable events, where CNC rates are going up and coachable event rates are going down, we are unsure whether specific triggers were more or less helpful in reducing CNC or coachable events.

The percentage-of-drivers analysis demonstrated some interesting trends in these data. First, there was a higher percentage of teenage drivers not involved in any crash or near-crash for Driver Coach Groups compared with the SPDS participants. This provides some corroborating evidence that the Driver Coach system reduced CNC occurrence for teens who had the system in their vehicle; however, we cannot rule out selection bias. Second, the teens whose parents did not log in had a higher number of teen drivers who were involved in four or more CNC events. What this result suggests is that there may have been some higher-risk teen drivers in this particular group. Future analyses should evaluate the interaction between high- and low-risk teen drivers versus highly involved and uninvolved parenting styles.

The analyses investigating driver error rates indicated that for all teen drivers the most frequently committed driver errors were vehicle control, speed selection, distraction, and hazard detection errors. These errors went down over time for teens whose parents monitored the coaching website but remained flat for those teens whose parents did not monitor the website. This suggests that parents had conversations with their teens about these errors and that the teenage drivers responded appropriately by reducing the frequency of poor speed selection and/or engaging in distracting tasks. Unfortunately, these errors were only recorded if a kinematic threshold was exceeded; thus, it could be that teenagers just learned to not engage in these types of activities if and when they were going to brake too hard or corner too hard. We would need to identify a sample of “normal” driving to assess whether these types of errors and behaviors truly decreased over time. Future analyses will hopefully allow for the coding of these data to better inform us of teenage driving behavior in the presence of real-time and post hoc feedback.

CNC rates are typically found to go down over time, even during the first seven months of driving.⁽⁷⁾ We did not find that to be true with CNC rates for this study or our control group (SPDS). There could be several possible explanations for this finding. One would be that there is a seasonal bias to our data. However, recruitment occurred over a period of 15 months for SPDS and 9 months for the DCS, and thus there appears to be no systematic seasonal biases to our data. Another potential option is that we have not fully identified all the CNCs that exist in these databases. This is highly unlikely, especially for the DCS, because the kinematic threshold for CNCs was lowered to identify coachable events. Thus, we should have nearly all of the CNCs in the data set. For SPDS, we initially coded validity for the triggered epochs and then reviewed to code severity (crash, near-crash, crash-relevant conflict). Invalid and crash-relevant conflicts were spot checked by expert researchers, who made some changes to the original coding, but the percentage of changes was low. Therefore, we are relatively confident that we have not overlooked any crashes or near-crashes. There may still be some outliers in these data; however, a cursory review of the individual CNC rates suggests that this is not likely. Although further analysis may make some adjustments, the overall findings presented here would likely not change significantly with one or two participants removed from the analysis.

CHAPTER 5. FUTURE WORK

The analyses presented here represent only a small component of the analyses that can be conducted with these rich data sets of novice and parent naturalistic driving. Further analyses of the role of parental monitoring and how it impacts teen driving performance could be conducted via the development of a novice driver baseline database. A baseline database would consist of randomly selected segments of video that are stratified based upon teen driving exposure. These segments of video would be coded for various driver behaviors, driver errors, and driver impairment, as well as the types of roadway and traffic environments. This baseline data set would allow the prevalence of secondary task engagement, risky driving behaviors, driver impairment, etc., to be evaluated over time. This would allow us to determine if teens whose parents were monitoring the website also exhibited lower rates of high-risk secondary task engagement, driver errors, etc.

Additionally, data were collected during the learner's permit period. These data are untouched and would provide information regarding types of roadways and traffic conditions that the Driver Coach participants were exposed to during their learner's permit period. Data could also be used to determine how well teens' parents taught them to drive during the learner's permit period. A comparison of parents who monitored the website versus those who did not could be evaluated to see whether monitoring parents are also better driver's education instructors, resulting in their teens being better drivers because of their training. Putting it differently, an analysis of the learner's permit phase of this study would allow researchers an opportunity to assess any deficiencies in their driving education. This would result in a better insight into the communication between teens and parents about driving and could, in turn, help with parent training and driver's education courses.

Driving data from the parents have also not yet been coded and remain unanalyzed. Comparison of parent drivers to teenage drivers would be an interesting analysis to determine whether teenagers' driving patterns are similar to those of their parents.

One of the benefits that the DCS has provided is that it has shown that feedback can lower CNC rates among novice drivers significantly when parents are engaged in the coaching process. This can be translated into future safety interventions as well as crash mitigation systems.

It could be argued that the findings of this study indicate that more research needs to be conducted on providing different forms of feedback to teens. Through a better understanding of what forms of feedback were best accepted and retained, the potential to dramatically reduce teens' CNC rates is possible. Focus groups, further analyses of questionnaire data, and teen and parent interviews could all provide insight into teens' and parents' opinions of the real-time and post hoc feedback. Analyses of which elevated g-force events pose the largest risk to teen driving safety could lead the way for creating more efficient feedback safety systems.

Additional criteria could also be added to improve teen driving. Hazard detection is a critical skill that many teen drivers lack. If feedback could be provided to inform the teenager of impending hazard (e.g., pedestrian detection system), teen crash rates could be further reduced. Additional development could be performed on the current hazard detection training systems to improve efficiency and reliability.

Future studies could be conducted on the level of parental involvement during the learner's permit phase and through early independent driving. Low website logins by parents indicate the importance of training and educating parents on the benefits of using the website to teach their teens how to drive. It may also be helpful to gather data on whether parents and teens looked at the website together. For this purpose, questionnaires could be developed to better prepare and support parents on how to best teach and discuss driving with their teens.

CHAPTER 6. CONCLUSIONS

The following conclusions can be drawn from the DCS:

- DCS teenagers whose parents monitored the website had lower relative rates of CNCs than SPDS teenage drivers.
- Once feedback was turned off, CNC rates increased significantly. Thus, six months of feedback was not enough time to instill habitually safe driving habits in novice teen drivers.
- Results suggest that real-time and post hoc feedback produce a relative reduction of the rate of all coachable events for teens whose parents logged in to the website.
- There do not appear to be any unintended consequences of the Driver Coach Feedback system as it currently is designed.
- The most frequent errors for teens were aggressive driving maneuvers, speeding greater than 5 mph but less than 15 mph over the speed limit, interacting with a cell phone, and not responding to traffic control devices properly.

CHAPTER 7. RECOMMENDATIONS

These results support current GDL policies and would encourage these policies to be strengthened, specifically GDL policies banning handheld cell phone use and teen passengers, as these are the most frequent types of distraction for teen drivers. We would also recommend the use of driver coach systems for teenagers and further education of parents on how to best use and incorporate these systems into the driver training of their teenagers. This would be a future study to determine how best to educate and assist parents in using the driver coach systems most effectively.

APPENDIX A. TEENAGE CRASH RATES IN VIRGINIA

We estimated the teenage crash rates in the state of Virginia using the crash data from VDOT and licensed teenage driver’s data from the DMV for the years 2010–2014. We estimated the teen crash rates present in each of the nine VDOT districts as shown in Figure A.1.



Figure A.1: Geographical representation of nine VDOT districts.

As shown below in Figure A.2, the crash rate per 100,000 licensed teen drivers of the Northern Virginia district was found to be the lowest, while Salem, Lynchburg, and Richmond have the highest crash rates (orange arrows). Our analysis also indicates that there is a statistically significant difference between the Northern Virginia district and the other eight districts.

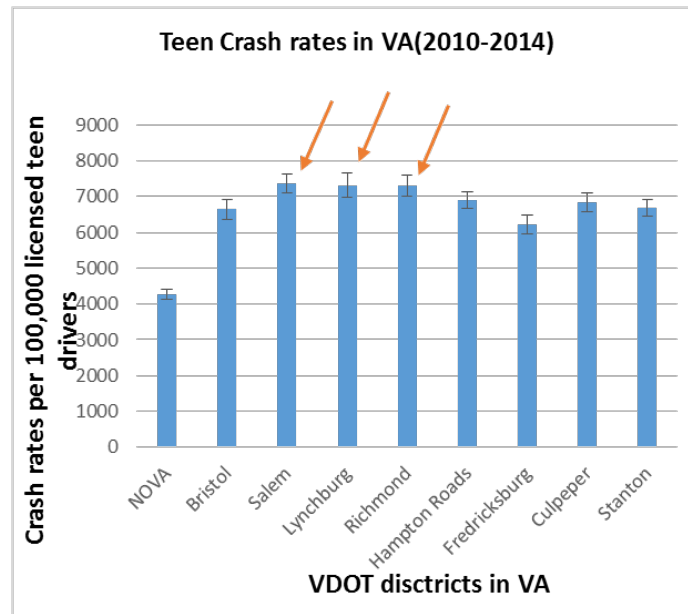


Figure A.2: Distribution of teen crash rates in VA among nine VDOT districts for 2010–2014.

Altogether, our analysis provides baseline teen crash rates prevailing in Virginia along with highlighting the “hot spots” (areas with high crash rates) where future research and interventions are needed to reduce the crashes and negative driving outcomes among teens.

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