Teens have the highest crash rate of any group in the United States.

Using Naturalistic Driving Data to Assess the Prevalence of Environmental Factors and Driver Behaviors in Teen Driver Crashes

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Title

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Acknowledgments

About the Sponsor

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Founded in 1947, the AAA Foundation in Washington, D.C. is a not-for-profit, publicly supported charitable research and education organization dedicated to saving lives by preventing traffic crashes and reducing injuries when crashes occur. Funding for this report was provided by voluntary contributions from AAA/CAA and their affiliated motor clubs, from individual members, from AAA-affiliated insurance companies, as well as from other organizations or sources.

Executive Summary

Objective, detailed and accurate information regarding the prevalence of factors with the potential to contribute to crashes is vital. In the past, the only way to obtain information for a large number of crashes was to use data collected from police reports. While information gathered this way is helpful, it has many limitations. More recently, in-vehicle event recorders (IVERs) have become a widely accepted means of gathering crash data both in research and real-world applications.

In this study, we conducted a large-scale comprehensive examination of naturalistic data from crashes that involved teenage drivers. Other naturalistic studies have investigated only a small number of crashes or used near crashes as a proxy for actual crashes, and few crashes involving teen drivers have been observed in other naturalistic studies. In contrast, this project examined naturalistic data from thousands of actual crashes that involved teenage drivers. The data allowed us to examine behaviors and potential contributing factors in the seconds leading up to the collision, and provided information not available in police reports.

A coding method was developed specifically for this study, and video data were coded with the goal of identifying the factors present prior to crashes—in particular the prevalence of potentially distracting driver behaviors and drowsiness. The study addressed the following research questions:
- What were the roadway and environmental conditions at the time of the crash?
- What were the critical events and potential contributing factors leading up to the crash and did these differ by crash type?
- What driver behaviors were present in the vehicle prior to the crash and did these differ by crash type?
- How did driver reaction times and eyes-off-road time differ relative to certain driver behaviors and crash types?
- Could drowsy driving be detected using this type of crash data?

Understanding the prevalence of potential contributing causes of crashes provides a significant societal benefit and advances the field of traffic safety. More specifically, information regarding what is happening inside the vehicle during the seconds before a crash can suggest countermeasures such as education, training, or advanced safety technologies that might best mitigate certain types of crashes.

METHODS

Lytx, a company that has been collecting data using in-vehicle event recorders (IVERs) for over a decade, provided the crash data. Their DriveCam system collects video, audio and accelerometer data when a driver triggers the device by hard braking, fast cornering, or an impact that exceeds a certain *g*-force. Each video is 12-seconds long, and provides information on the 8 seconds before and 4 seconds after the trigger. The system has a wide range of applications—families use them to help young drivers as they begin to drive independently, while over 500 commercial and government fleets employ them for fleet management.

Crashes examined in this study involved drivers aged 16-19 who were participating in a teen driving program that involved the use of a DriveCam system. Ltyx made 6,842 videos of crashes that occurred between August 2007 and July 2013 available for review. In order to reduce this number and to eliminate minor curb strikes from the analysis, those crashes in which the vehicle sustained forces less than 1g were excluded. Crashes in which the DriveCam equipped vehicle was struck from behind were excluded. Additional videos were excluded for other reasons (e.g., animal strikes, video problems, or the driver not being a teen). A total of 1,691 moderate-to-severe crashes met the inclusion criteria and were analyzed for the current study.

Video from the 6 seconds preceding each crash were coded for analysis. A coding methodology which focused on identifying the factors present in crashes was developed specifically for gathering information from the videos. Data elements coded for each crash included environmental conditions, contributing circumstances (e.g., inadequate surveillance, running traffic signals), and driver and passenger behaviors. Each crash was double coded by two University of Iowa (UI) analysts and mediated by a third when necessary.

RESULTS

For this study, 1,691 moderate-to-severe crashes involving young drivers ages 16-19 were reviewed. Of these crashes, 727 were vehicle-to-vehicle crashes in which the force of the impact was 1.0g or greater, and 964 were single-vehicle crashes in which the vehicle's tires left the roadway and impacted (with a force of 1.0g or greater) one or more natural or artificial objects. While the extent of any injuries sustained in the crashes was not evident from the videos, it is known that no fatal crashes were included in this analysis. Additionally, while it is likely that most of the vehicle-to-vehicle crashes in the analyses resulted in a police report being filed, many of the single-vehicle crashes may have gone unreported.

Characteristics of drivers and passengers
Male drivers were involved in 52% of crashes and females 48%. When drivers were examined by crash type, results indicated that more males were involved in single-vehicle crashes than females (56% vs 44%), and more females in vehicle-to-vehicle crashes than males (53% vs 46%). The driver was seen wearing a seatbelt in 93% of all crashes. Passengers were present in the vehicle in one-third of crashes (36%), with one passenger present in 25.5% and two or more passengers present in 10.5%. One-quarter (27%) of crashes with passengers showed at least one passenger that was unbelted. The majority of passengers, when present, were estimated to be 16-19 years old (84%); 55% of the passengers were male.

Characteristics of roadway and environment
In general, crashes occurred most often on roadways that connect local streets, called collectors (52%). However, when examined by crash type, single-vehicle crashes were more likely to occur on collectors than vehicle-to-vehicle crashes (66% vs 35%), and vehicle-to-vehicle crashes were more likely than single-vehicle crashes to occur on arterials (47% vs 8%). Road surface conditions were more likely to be dry for vehicle-to-vehicle crashes than for single-vehicle crashes (79% vs 19%); a much greater proportion of single-vehicle crashes

than vehicle-to-vehicle occurred on roads covered with snow or ice (65% vs 8%). Overall, 60% of crashes occurred when there was no adverse weather; however, this was significantly more likely to be the case for vehicle-to-vehicle crashes than for single-vehicle crashes (74% vs 48%).

Vehicle-to-vehicle crashes were more likely to happen during the week than single-vehicle crashes (79% vs 65%), with more occurring on Friday than any other day. In addition, vehicle-to-vehicle crashes were significantly more likely than single-vehicle crashes to occur between 3pm and 6pm (36% vs 19%). In contrast, single-vehicle crashes were more likely to occur on a weekend (35% vs 21%) and nearly three times as likely to occur between 9pm and midnight (14% vs 5%).

Characteristics of crashes
Recognition errors (e.g., inattention and inadequate surveillance) and decision errors (e.g., failing to yield right of way, running stop signs and driving too fast) were the most common errors made by young drivers, occurring in 70% and 66% of all crashes, respectively. However, when examined by crash type, recognition errors were significantly more common in vehicle-to-vehicle crashes than in single-vehicle crashes (89% vs 56%). In addition, both performance errors (e.g., losing control and overcorrecting) and decision errors were significantly more frequent in single-vehicle crashes (82% vs 9%, and 80% vs 47%, respectively).

Characteristics of vehicle-to-vehicle crashes
The majority of vehicle-to-vehicle crashes were rear-end (57%) and angle (40%) crashes. Eighty-eight percent of rear-end crashes in which the DriveCam-equipped vehicle struck a lead vehicle involved another vehicle in the driver's lane decelerating or stopping on the roadway. (Rear-end crashes in which the DriveCam-equipped vehicle was struck from behind were not included in this analysis.) Of angle crashes, 58% involved the participant's vehicle crossing the centerline or turning at an intersection; 38% involved another vehicle encroaching on the participant's vehicle. Regardless of fault, in 94% of crashes the driver potentially contributed to the crash in some way. Decision errors such as a failure to yield right of way (ROW) and running stop signs/signals were significantly more frequent in angle crashes than in rear-end crashes (61% vs 38%). Recognition errors such as inadequate surveillance and inattention, as well as performance errors such as losing control of the vehicle, were more frequent in rear-end crashes than in angle crashes (93% vs 82%, and 11% vs 5%, respectively).

Characteristics of single-vehicle crashes
Of the single-vehicle crashes coded, 66% were loss-of-control (LOC) crashes due to road surface or weather conditions combined with travelling too fast for the conditions; 19% were road-departure crashes attributed to driver inattention due to distraction or inadequate surveillance; 12% were LOC crashes attributed to excessive speed (not related to road or weather conditions); and 3% were LOC due to an evasive maneuver. Only one crash was attributed to LOC due to mechanical failure (a brake failure was evident in one crash). Regardless of fault, the driver was considered to have potentially contributed in some way to 99% of the crashes. Recognition errors (i.e., inadequate surveillance or inattention) were present in 100% of road-departure crashes compared to only 46% of LOC crashes. Decision errors such as driving too fast and following too closely were more common in LOC crashes than in road-departure crashes (99% vs 4%). Finally, performance errors such as losing

control of the vehicle and overcorrecting/over steering were also more common in LOC crashes, present nearly 100% of the time, compared to only 12% of road-departure crashes.

Driver behaviors
Drivers were seen engaging in some type of potentially distracting behavior leading up to 58% of all crashes examined. The two most frequently seen driver behaviors were attending to passengers (14.9%) and cell phone use (11.9%). Cell phone use was significantly more likely in road-departure crashes than any other type of crash (34% vs 9.2%). Attending to a passenger was slightly less likely to be seen during a road-departure crash than any other crash types (13.3% vs 15.0%). Overall, males and females were equally likely to be engaged in potentially distracting behavior. However, females were more likely than males to have been using a cell phone (14% vs 10%), engaged in personal grooming (7% vs. 5%), or singing/dancing to music (9% vs 6%) prior to the crash. Additionally, for all types of crashes, drivers were significantly more likely to have been using their cell phone when they were alone in the vehicle than when they had passengers.

Drivers were found to have been looking away from the roadway for a significantly longer length of time prior to the crash in road departure crashes than in any other type of crash; mean eyes-off-road times were 4.0s for road departure crashes, 2.5s for rear-end crashes, 0.7s for angle crashes, and 0.5s for LOC crashes.   Of all driver behaviors, using electronic devices, attending to a moving object in the vehicle, using a cell phone and reaching for an object resulted in the longest mean eyes-off- road times (3.9s, 3.6s, 3.3s, and 3.3s, respectively). Drivers engaged in cell phone use had mean eyes-off-road times that were twice as long as those drivers who were attending to passengers (3.3s vs 1.5s). Also, when cell phone use was analyzed separately, the average eyes-off-road time for drivers who were operating or looking at their phone was 4.1s, compared to 0.9s for drivers who were talking or listening.

Reaction time was analyzed for rear-end crashes only. Results found that drivers who were using a cell phone had a significantly longer reaction time than drivers not engaged in any behaviors (2.8s vs 2.1s). In contrast, drivers attending to passengers had similar reaction times to drivers not engaged in any behaviors (2.2s vs 2.1s). In addition, in over 50% of rear-end crashes where the driver was engaged in cell-phone us, the driver showed no reaction at all (braking or steering), whereas the driver failed to react at all in only 9.5% of crashes with a driver attending to a passenger.

Passenger behaviors
Passengers were present in 36% of the crashes. The majority of passengers present in the crashes examined were estimated to be 16-19 years old (84%), and 55% were male. Overall, the most frequent behavior that passengers were seen engaging in was conversation with the driver. When single passengers were present, they were engaged in conversation with the driver 36% of the time, and when two or more passengers were present, 39% of the time. When two or more passengers were present, they were significantly more likely to be making loud noises (5% vs 0.2%), moving around in the vehicle (14% vs 6%) and texting/using cell phone (7% vs 3%) than when only a single passenger was present.

Drowsy driving
Determining whether or not a driver was drowsy was extremely difficult given the limitations associated with event-triggered naturalistic driving data. Only 15 of the 1,691

crashes reviewed contained conclusive evidence of drowsy driving; however, it is possible that drowsiness was present in cases in which it could not be ascertained with only 6 seconds of pre-crash video.

SUMMARY

Use of IVERs in naturalistic driving allows researchers a unique view into the vehicle and provides invaluable information regarding the behavioral and environmental factors present before a crash. The data gathered offers a much more detailed context relative to police reports and other crash databases, and allows more micro-level analyses to be conducted.

This study examines the roadway and environmental conditions present in different types of crashes. It describes the critical events and contributing factors that led to crashes, and how they varied by crash type. It also provides information regarding the possible effect certain driver behaviors could have on reaction time and eyes-off-road time. Finally, it is the first and largest naturalistic study of moderate-to-severe crashes to examine driver and passenger behaviors for a variety of crash types.

As was expected, environmental and roadway conditions varied considerably by crash type, with single-vehicle crashes being most affected by weather and surface conditions. Time of day also played a role, with single-vehicle crashes being more likely to occur at night, while vehicle-to-vehicle crashes were more likely during times of high traffic flow. Recognition errors were more common for vehicle-to-vehicle crashes, while performance errors were more frequent in single-vehicle crashes. While drivers were seen engaging in a wide range of behaviors leading up to a crash, the most common behavior among young drivers was attending to passengers. When passengers were present, the most common behavior they engaged in was conversation with the driver. Cell phone use was also seen frequently for all drivers, with operating/looking at the phone (e.g., texting) observed most often.

Interestingly, all drivers were significantly more likely to be using a cell phones (for talking or texting) when they were alone in the vehicle. Cell phone use was more common in road departure crashes and contributed to significantly longer reaction times. Potentially distracting behaviors in general, and cell phone use in particular, were much more prevalent in the current study than in official statistics based on police reports. One unexpected result was that reaction times were not significantly longer when drivers were attending to passengers than when they were not. The results of this study can be used to inform the development of education, training, and technology-based interventions aimed at reducing teen drivers' crash risk.

Introduction

Motor vehicle crashes are one of the leading causes of death for teens in the United States. According to the National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS), 33,561 people were killed in motor vehicle traffic crashes in 2012. Young drivers ages 15-20 were involved in 4,283 of those fatal motor vehicle crashes (Traffic Safety Facts, 2014). These numbers underline the importance of this issue, and why it continues to merit our attention. It is crucial that we continue to examine the events that lead to motor vehicle crashes in order to try to develop effective countermeasures to prevent crashes, injuries, and deaths. However, due to the substantial limitations of available crash data, there is little objective scientific knowledge about the circumstances involved in teen driver crashes.

Previously, the only way to study teen driver crashes was to use large administrative databases such as NHTSA's FARS and the National Automotive Sampling System (NASS) General Estimates System (GES). FARS collects fatal crash data from all 50 states, the District of Columbia and Puerto Rico. NASS GES comprises a nationally representative sample of police-reported crashes of all police-reported crashes nationwide irrespective of severity. However, these sources of data suffer from substantial limitations including: (1) only police-reported crashes are included, which are only a percentage of the crashes that occur, and which contain information that varies across jurisdictions and states; and (2) they provide limited information regarding the role of behavioral factors due to a lack of physical evidence at the scene as well as driver's inability to remember or unwillingness to admit to the contribution of their pre-crash driving behavior to the occurrence of the crash.

Over the past 10 years, however, the traffic safety research community has developed new and increasingly sophisticated means of collecting and analyzing traffic safety data to provide new insights into crash causation. However, naturalistic studies using these in-vehicle technologies can be expensive to conduct, so they typically involve small samples, and therefore, a small number of actual crashes. This is the first study to examine a large number of teen driver crashes observed via in-vehicle technology. In addition to examining the pressing issues surrounding teen driver distraction, this study was able to examine the following:
- The roadway and environmental conditions at the time of the crash.
- The critical events and contributing factors leading up to the crash.
- Driver behaviors present in the vehicle and whether they differed by crash type.
- Changes in driver reaction times and eyes off road times relative to driver behaviors and crash types.
- Whether drowsy driving could be detected using this type of crash data.

Methods

Development of coding methodology

To examine the factors associated with young driver crashes, it was first necessary to develop an extensive, yet focused, coding methodology. Numerous crash databases and coding methodologies from the government sector were reviewed (see Table 1). Government sources included: the Model Minimum Uniform Crash Criteria (MMUCC); the NHTSA's FARS and NASS GES data systems; and NHTSA's National Motor Vehicle Crash Causation Survey (NMVCCS). In addition, since there is some variation in states' Police Accident Reports (PARs), we reviewed the reports and the coding overlay forms for all 50 states. We also examined the European crash data set variables and methodology (CADaS).

However, the data that can be obtained using IVERs is different from that acquired at the scene of a crash by law enforcement. IVERs most often provide video as well as audio, giving the reviewer invaluable information regarding the environment both inside and outside the vehicle prior to the crash including valid information regarding potential distractions. Information such as speed and the force of the impact is also available when using these types of systems. The University of Iowa (UI) and Virginia Tech Transportation Institute (VTTI) have developed coding methods for these new types of data (see Table 2). Both of their coding methodologies were reviewed for data elements of interest. Additional academic sources for coding driving behavior included Stutts et al., 2003, and Heck and Carlos, 2008. These sources focused mainly on distraction coding.

Table 1. Government sources of coding methodologies for crash data.

Coding Source	Source Type	Description
PARs for all 50 states	Government	Each state is required to have a highway safety program for accident investigation and reporting. While this helps ensure consistency within the state, it does little to address the need for a uniform and consistent means for obtaining national data. Each state uses a unique PAR, with data variables and definitions that can be inconsistent and require recoding at the national level.
MMUCC (4th edition, 2012)	Government	Recommends a set of standardized data elements, 77 of which are collected at the crash scene by law enforcement. This program is funded by NHTSA, and jointly managed by NHTSA and the Governor's Highway Safety Administration (GHSA), with input from the U.S. Department of Transportation (DOT).
FARS/NASS GES 2011	Government	• FARS provides annual data regarding fatal traffic crashes to NHTSA. These data are collected from PARs. • NASS GES focuses on the bigger overall crash picture, and is used to identify problems and trends. The data is gathered from a nationally representative sample of police-reported crashes—including both fatalities and injury crashes. While these two data systems remain separate, a standardization of the data elements between the two was completed in 2011, so that they now share a uniform set of data elements including: crash, vehicle, driver, pre-crash, motor vehicle occupant and non-motor vehicle occupant.
NMVCCS	Government	NHTSA completed a national, three-year study of crashes (2005-2007), with a focus on factors related to pre-crash events. Crash data was collected on-scene for approximately 600 data elements to capture information related to the driver, vehicles, roadway and environment.
CADaS	National/European	The European Road Safety Observatory (ERSO) was developed under the SafetyNet project. Its objective is to support all aspects of road and vehicle safety policy development at both the European and national level. Included in this was the development of a new fatal and in-depth accident causation database. The Common Accident Data Set (CADaS) includes a common structure of standard data elements and values to allow for more detailed and reliable analyses at the European level.

Table 2. Academic sources of coding methodologies for crash data.

Coding Source-Academic	Description
McGehee et al., 2007; Carney et al., 2010; McGehee et al., 2013	The UI has conducted several naturalistic driving studies over the last 10 years. Naturalistic data gathered includes safety-relevant driving events, near crashes and crashes. The goal of this research was to identify driver errors and provide drivers with feedback to minimize their involvement in safety-relevant/critical events. Detailed frame by frame analyses were conducted for each crash and near-crash captured by the system.
Neale et al., 2005; Klauer et al., 2006; Dingus et al., 2006	The 100-car study conducted at the VTTI examined the driving of 100 drivers over the course of one year. Naturalistic data gathered includes safety-relevant driving events, near-crashes and crashes, and was coded to gain a greater understanding of pre-crash causal and contributing factors.

From the review of government, industry and academic sources, a comprehensive list of 64 data elements relevant to the current project was compiled and entered into a spreadsheet. Due to constraints imposed by cost, time, and the technology, it was necessary to systematically reduce the number of data elements based on a set of project design goals.

The next step was to determine whether or not the information for coding the data element was attainable via the DriveCam video. This video consists of a 12-second clip—8s before the triggering event and 4s after. (Please note, however, to ensure results were comparable to other naturalistic driving studies that have examined crashes, only the 6s prior to the trigger were considered.) The video includes a view of both the interior and exterior of the vehicle (Figure 1) as well as audio. There is an approximately 120-degree field of view out the front windshield with a resolution of 256 x 200 pixels and a frame rate of 4 Hz (four frames per second). Due to these constraints, it was determined that it would not be possible to obtain the information necessary for coding five of the 64 data elements (e.g., extent of damage and severity of injuries), and that nine would be codable only some of the time (e.g., number of hands on wheel, vehicle speed). The five uncodable elements were eliminated from further analysis.

Figure 1. View of DriveCam video

A modified trade analysis was conducted for the remaining 59 data elements (Mollenhauer et al., 1997; McGehee & Raby, 2002). This process allows one to choose between alternatives based on the relative importance of critical criteria. For our purposes, we used it to narrow down and select those data elements that best met the study objectives. The critical criteria used to make the selections were: (1) relevance to the project; (2) ability to code reliably; and (3) the effort necessary to code. These criteria were then weighted from one to 10, with a higher number indicating greater importance relative to the study objectives. A set of experts in the field of naturalistic video coding independently weighted the criteria and negotiated the final weighting. Operational definitions of the criteria, their associated weights and rationales for weighting are presented in Table 3.

Table 3. Critical criteria and their assigned weights

Criteria	Weight	Operational Definition	Expert Rationale for Weighting
Relevance to the project	10	The degree to which the data element provides information directly related to crash causation	Data elements most directly related to determining crash causation should receive the greatest consideration.
Ability to code reliably	6	The likelihood that multiple reviewers would be able to code the data element in an identical way.	The ability of the analysts to apply the codes for the data element in a consistent manner deserves moderate consideration.
Effort necessary to code	3	The amount of effort required to obtain/calculate the information from the DriveCam video and code the data element.	Effort required to code the data elements should only be a minor consideration and is only included due to the large number of crashes and time constraints of the project.

Next, the experts scored the individual data elements on a scale of one to five for each of the criteria. This is the most difficult and subjective part of the trade analysis, and works best when performed by multiple expert raters. To aid in this process, the scoring was operationally defined (Table 4).

Table 4. Scores assigned to each of the critical criteria

Criteria	Scoring
Relevance to the project	5- the data element is related to fatigue, distraction 4- the data element is related to other crash causation factors 3- the data element can be used to infer crash causation 2- the data element is important information for crashes but does not help determine cause 1- the data element is not at all relevant to the project goals
Ability to code reliably	5- codes are objective and mutually exclusive 4- codes are objective but **not** mutually exclusive 3- codes are subjective and mutually exclusive 2- codes are subjective and **not** mutually exclusive 1- coding reliably is extremely unlikely if not impossible for this data element
Effort necessary to code	5- the data element is provided in the event details tab 4- the data element is visible on the initial screen shot in the video 3- the data element is visible in the video but requires the reviewer to watch the entire video 2- the data element requires a frame by frame analysis 1- the data element requires the coder to "dig" for the information

A trade study matrix was then generated to help calculate the weighted scoring. From this, we were able to narrow the data elements to be coded down to a focused set specific to the project. Twenty-four data elements were identified for inclusion in the final coding plan aimed at obtaining crash causation information.

After final review by an additional expert analyst and the AAAFTS, the final coding variables were determined (see Appendix A for a list of all variables and their definitions). Four broad categories of coded variables included: (1) general background and environmental variables; (2) variables specific to the crash; (3) variables specific to the driver; and (4) variables specific to passengers. These are described below.

General background and environmental variables, including:
- Month, day, and year
- Time
- Weather
- Light conditions
- Road surface conditions
- Road type
    – *Interstates - high speeds over long distances—speeds usually 55mph or greater*
    – *Arterials - freeways and multi-lane highways, connect urbanized areas, cities, and industrial centers—speeds usually 45-65mph*
    – *Collectors - major and minor roads that connect local roads and streets with arterials, balance mobility with land access—speeds usually 30-45mph*
    – *Local - limited mobility, primary access to residential areas and businesses— speeds usually not greater than 25mph*

Variables specific to the crash, including:

- Forward and lateral *g*-force at time of impact
- Vehicle speed immediately before crash (available for < 10% of crashes)
- Magnitude of crash (calculated using the lateral and forward g-forces at impact)
- Impact location
- Manner of collision
- Critical precipitating event
- Contributing circumstances, Driver
- Contributing circumstances, Environment
- Contributing circumstances, Roadway
- Airbag deployment

In addition to the variables listed above, driver errors were identified based on the driver's potential contribution to the crash. We considered four types of driver errors; recognition, decision, performance and non-performance (Treat et al., 1979; Curry et al., 2011). Recognition errors were those associated with inattention and distraction. Decision errors included driving too fast for the conditions, running stop signs/traffic signals, driving too closely, and failing to yield right-of-way. Performance errors included inability to control the vehicle or overcompensating. Non-performance errors included drivers who were fatigued or tired. Some crashes involved a combination of these errors. Each type of error is defined below in Table 5.

Table 5. Types of driver errors coded in this study.

Driver Error Type	Driver Contribution to Crash
Recognition Errors	Inadequate surveillance Inattentive/engaged in extraneous behaviors
Decision Errors	Driving too fast Failed to yield Right of Way (ROW) - At uncontrolled intersection Failed to yield ROW - Entering roadway Failed to yield ROW - From driveway Failed to yield ROW - From stop sign Failed to yield ROW - Making left turn Failed to yield ROW - Right on red Followed too closely Misjudged gap Operating in a reckless manner Other illegal maneuver Ran stop sign Ran traffic signal Travelling wrong way Unsafe lane change Made improper turn
Performance Errors	Crossed centerline Lost control Overcorrecting/over steering
Non-performance Errors	Tired/falling asleep

It should be noted that while we attempted to code vehicle speed, it was available for less than 10% of all crashes. We were able to make relative judgments of speed based on traffic and road conditions, and to code 'driving too fast' when we felt that the driver was exceeding a safe speed relative to traffic or to the roadway conditions. When present, this was coded as a driver contribution to the crash.

Variables specific to the driver were also coded. These included:
- Age
- Gender
- Behavior (e.g., cell phone use, talking with passengers, eating)
- Condition (e.g., emotional, asleep, under the influence)
- Vision obscured by (e.g., glare, weather or an improperly cleared windshield)
- Hands on wheel
- Number of glances off roadway
- Total number of frames the eyes were off roadway
- Total time eyes were off roadway
- Duration of longest glance
- Reaction time (for rear-end crashes only)
- Inadequate surveillance
  - *Coded when traffic signals/signs were missed*
  - *Coded when braking reaction times were poor (>1s)*
  - *Coded when the Total eyes off roadway time was >2s*
- Seatbelt non-use

It is important to note that reaction times were only calculated for the vehicle-to-vehicle rear-end crashes. These crashes were unique in that there was a specific event (i.e., the onset of lead vehicle brake lights) from which a reaction time could be calculated. The driver reaction time was calculated from the onset of the lead vehicle brake lights until the driver actively braked (>0.15g). If the driver did not respond (i.e., brake or steer) before the crash, no reaction time (NRT) was coded. The calculation of reaction time was done using video analyzed at 4 frames per second, meaning that determination of brake onset could not be precise. However, we determined that it would still be able to make relative judgments using this measure.

Multiple driver behaviors could be present in the vehicle leading up to the crash. Each one was coded. Some crashes included as many as four behaviors. Analysts made no judgments as to whether the driver was actually distracted by the behavior—they simply coded what was occurring inside the vehicle at the time of the crash. Table 6 shows the behaviors coded.

Variables specific to the passenger(s) present in the vehicle were also coded. These included:
- Age (estimated)
- Gender
- Behavior
- Social Influence
- Seatbelt non-use

Table 6. Driver behaviors coded for all crashes in this study.

Behavior	Definition or Description
Talking to self	Driver is talking out loud without a passenger or audience in the vehicle
Reading	Driver is reading or looking at map/book/papers
Attending to passenger(s)	Driver is looking at, in conversation with, or otherwise interacting with passenger(s)
Attending to a moving object	Driver is looking at an object/animal moving around inside the vehicle
Use of cell phone (talking/listening)	Driver is having a conversation with another party using a cell phone
Use of cell phone (operating/looking)	Driver is looking at/manipulating a cell phone (i.e., texting, surfing)
Use of cell phone is likely but not visible	Driver is likely operating/looking at cell phone but device is out of view of the camera
Adjusting controls	Driver is operating some in-vehicle control
Using electronic device	Driver is looking at and/or manipulating a device other than a cell phone brought into the vehicle (i.e., mp3, iPod, nav system)
Reaching for object	Driver is picking something up, putting something down, or handing object to another person
Eating or drinking	Driver is putting food or drink to mouth
Smoking related	Driver is lighting, smoking or extinguishing cigarette
Personal grooming	Driver is engaged in some form of personal hygiene, with or without mirror glance (i.e., fixing hair, picking teeth)
Singing or dancing to music	Driver is singing (regardless of volume) or moving any part of their body to the music
Attending to person outside the vehicle	Driver is looking at or communicating with someone outside of the vehicle (i.e., pedestrians)
Attending to another vehicle or passengers of another vehicle	Driver is looking at another vehicle or communicating with its passengers
Attending inside the vehicle, unknown	Driver is looking at something of unknown location inside the vehicle
Attending outside the vehicle, unknown	Driver is looking at something of unknown location outside the vehicle (not at the forward roadway)
Attending elsewhere, unknown	Driver is looking somewhere other than forward roadway, unknown

Multiple passenger behaviors could be coded for each crash. The behaviors that were coded were similar to those used by Heck and Carlos (2008), but were modified slightly to include the use of cell phones by passengers. Table 7 shows the passenger behaviors coded for this study. Note that when a passenger was talking to the driver this was *only* coded as a passenger behavior as it could not be assumed that the driver was attending to the passenger. Only when the driver was looking at the passenger or clearly engaged in the conversation were they coded as engaging in a secondary behavior.

Table 7. Passenger behaviors coded for all crashes in this study.

Behavior	Definition or Description
Engaged in conversation with driver	Passenger is talking to the driver
Engaged in conversation with other passenger(s)	Passenger is talking to other passenger(s)
Emotional	Passenger is visibly angry or upset
Singing	Passenger is singing (regardless of volume)
Yelling	Passenger is yelling (speaking extremely loud)
Making loud noises	Passenger is whistling, screaming, etc.
Smoking related	Passenger is lighting or extinguishing cigarette
Moving around in vehicle	Passenger is turning around in seat, wrestling, dancing
Adjusting vehicle controls	Passenger adjusts in-vehicle controls
Giving directions	Passenger is helping the driver navigate (telling them where to go or where to turn, etc.)
Showing driver something	Passenger points something out to the driver, shows them something
Talking on the phone	Passenger is talking on a cell phone
Texting/using cell phone	Passenger is texting or surfing on their phone
Reaching for something	Passenger is picking something up, putting something down or passing something to someone
Purposely distracting driver	Passenger is poking, kissing, tickling, grabbing or hitting driver

Additional variables were added to the coding scheme when single-vehicle crashes were analyzed in order to capture their unique nature, including: edge type, pre-crash movement, sequence of events, and conflict classification. Other variables were removed, as they were not available or not relevant for single-vehicle crashes (in particular, impact zones and reaction times). The revised coding sheet used for coding single-vehicle crashes, including variable definitions, can be found in Appendix B.

Crash coding

Once the full coding method was complete, we turned to coding the crashes. Vehicle-to-vehicle crashes were coded first. The majority fell into two categories of crashes: rear-end and angle. A rear-end crash occurs when the driver collides with the rear of another vehicle, while the two vehicles are traveling in the same direction. An angle crash occurs when two motor vehicles impact at an angle, such as when the front of one motor vehicle collides with the side of another. No determination was made regarding which vehicle was the striking vehicle and which was being struck.

Single-vehicle crashes were the second category of crashes to be coded. These crashes included loss-of-control (LOC) and road-departure crashes. LOC crashes occur most often when a driver either overcorrects/oversteers or understeers, and as a result, the vehicle

departs the roadway. These types of crashes occur most often on curves or poor road surface conditions. A road-departure crash does not involve a driver action before the vehicle departs the roadway, such as when the vehicle drifts out of the travel lane and off of the roadway surface on a straight section of road or when the vehicle continues straight and makes no attempt to negotiate a curve on a curved section of road. These types of crashes occur most often when a driver is inattentive or distracted.

Crashes examined

Crashes examined in this study involved young drivers ages 16-19 who were enrolled in a teen driving program that involved the use of the DriveCam system. The program provides both the teen and their family with weekly web-based feedback regarding the young drivers' performance and promotes safe driving behaviors. Video and other data from crashes involving program participants that occurred between August 2007 and July of 2013 were identified by Ltyx and were provided to the UI. The majority of the crashes occurred in Arizona, Colorado, Illinois, Iowa, Minnesota, Missouri, Nevada, and Wisconsin.

A total of 6,842 crash videos were obtained. A UI analyst reviewed each video to determine its relevance to the project goals. Figure 2 shows the review process and illustrates how we determined the videos to be used in the final analyses. A total of 3,785 crashes were identified as minor, with maximum lateral and longitudinal g-forces of less than 1.0 g. Because the goal of this project was to examine moderate-to-severe crashes, these minor crashes were not coded or included in the analysis.

The remaining 3,057 videos were classified as follows: approximately 60% were identified as vehicle-to-vehicle crashes and 40% single-vehicle crashes. Upon further review, 60% of the vehicle-to-vehicle crashes (1125 of 1852) were determined to be unusable for a variety of reasons (e.g., deer strikes, empty vehicles, interior or forward view unavailable, videos that would not open). The most frequent reason that vehicle-to-vehicle crashes were determined to be unusable was that the crash involved the vehicle containing the DriveCam being hit from behind. These crashes were not coded because information pertaining to what had caused the crash was generally unavailable. Additional crashes identified as "Other" were ones in which the reviewers were not able to discern the events surrounding the crash sufficiently for coding purposes. Once the unusable crashes were eliminated, 727 vehicle-to-vehicle crashes remained for coding and further analyses.

Only 12% (143 of 1,205) of the single-vehicle crashes were determined to be unusable (e.g., two vehicles were involved in the crash, there was no interior or forward view, or it was determined that the driver was not a teen). An additional 98 videos (8%) were the second or third video from a single event (i.e., the crash lasted longer than the 12-second video triggering additional videos). Therefore, 964 single-vehicle crashes remained for further coding and analysis.
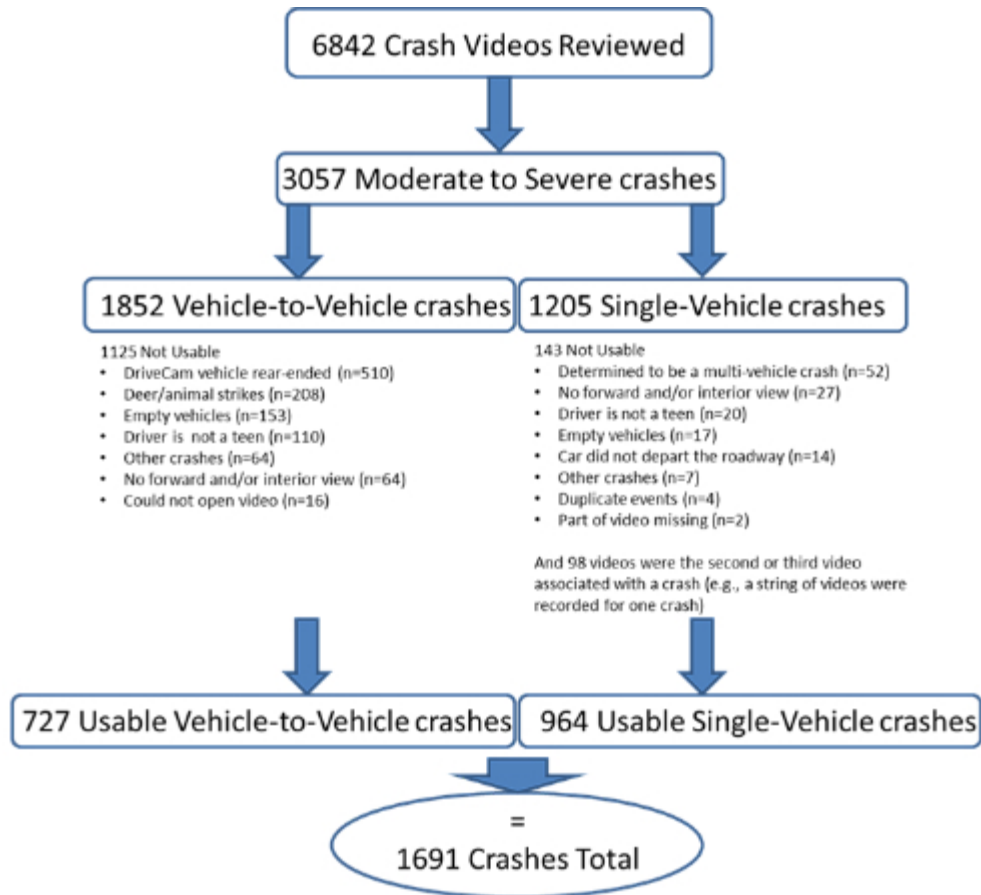
Figure 2. Breakdown of crash videos used in analyses.

The crash videos were 12-seconds long, capturing 8s before the trigger and 4s after it. However, to compare our results against previous naturalistic studies that have examined crashes (i.e., The 100 car study, Klauer et al., 2006), the 6s leading up to the crash was the period of interest for this study. Each crash was coded by two independent reviewers. The data files were then merged, and any discrepancies were identified. If the discrepancy was due to an error, it was corrected in the data file. However, if the discrepancy was due to a disagreement, the event was turned over to a third reviewer for mediation. Glance durations and reaction times differing by even as little as 1 frame (0.25 s) were mediated in an attempt to achieve the highest possible level of accuracy.

To assess the statistical significance of differences in proportions, the Pearson's chi-square test (all cell sizes greater than or equal to 5) or a Fisher's exact text (cell size less than 5) was used. To examine differences in means, the student's *t*-test was used. All analyses were completed using SAS version 9.4® (SAS Institute Inc., Cary, North Carolina).

Results

Characteristics of drivers and passengers

The 1,691 crashes analyzed involved young drivers between the ages of 16 and 19 years. A summary of the driver and passenger characteristics is presented in Table 8. Male drivers were involved in 52% of crashes and females 48%. The driver was seen wearing a seatbelt in 93% of all crashes. Passengers were present in the vehicle in one-third of crashes (36%) with one passenger present in 25.5% and two or more passengers present in 10.5%. One-quarter (27%) of crashes with passengers showed at least one passenger that was unbelted. The majority of passengers, when present, were estimated to be 16-19 years old (84%); 55% were male.

When drivers were examined by crash type, results indicated that there were more males involved in single-vehicle crashes than females (56% vs 44%, p<.01) and more females involved in vehicle-to-vehicle crashes than males (53% vs 46%, p<.01). Both drivers and passengers were more likely to be wearing a seatbelt during vehicle-to-vehicle crashes than single-vehicle crashes (96% vs 92%, p<.01; 79% vs 69%, p<.01, respectively).

Table 8. Characteristics of teen drivers and passengers by crash type

	Single-vehicle (n=964)	Vehicle-to-vehicle (n=727)	Total (n=1691)
Driver sex[2]			
Male	538 (55.8%)	337 (46.4%)	875 (51.7%)
Female	425 (44.1%)	388 (53.4%)	813 (48.1%)
Unknown	1 (0.1%)	2 (0.3%)	3 (0.2%)
Driver belted[2]			
Yes	885 (91.8%)	695 (95.6%)	1580 (93.4%)
No	79 (8.2%)	32 (4.4%)	111 (6.6%)
Passenger present			
None	639 (66.3%)	444 (61.1%)	1083 (64.0%)
One	231 (24.0%)	200 (27.5%)	431 (25.5%)
Two or more	94 (9.7%)	83 (11.4%)	177 (10.5%)
All passengers belted[2]			
Yes	223 (68.6%)	223 (78.8%)	446 (73.4%)
No	102 (31.4%)	60 (21.2%)	162 (26.6%)
Passenger age (approximate)	n=456 passengers in 325 events	n=408 passengers in 283 events	n=864 passengers in 608 events
1 to 4	2 (0.4%)	2 (0.4%)	4 (0.5%)
5 to 10	10 (2.2%)	11 (2.7%)	21 (2.4%)
11 to 15	42 (9.2%)	38 (9.3%)	80 (9.3%)
16 to 19	388 (85.1%)	337 (82.6%)	725 (83.9%)
20 to 29[2]	0	5 (1.2%)	5 (0.6%)
30 to 64	14 (3.1%)	12 (2.9%)	26 (3.0%)
65 +	0	3 (0.7%)	3 (0.3%)
Passenger sex			
Male	261 (57.2%)	213 (52.2%)	474 (54.9%)
Female	190 (41.7%)	194 (47.5%)	384 (44.4%)
Unknown	5 (1.1%)	1 (0.2%)	6 (0.7%)

[1]p<.0001, [2]p<.01, [3]p<.05

Characteristics of roadway and environment

In general, crashes occurred most often on collectors (52%). However, when examined by crash type (Table 9), single-vehicle crashes were more likely to occur on collectors (66% vs 35%, p<.0001) and vehicle-to-vehicle crashes were more likely to occur on arterials (47% vs 8%, p<.0001). Road surface conditions were more likely to be dry for vehicle-to-vehicle crashes (79% vs 19%, p<.0001) and more likely to be covered with snow or ice for single-vehicle crashes (65% vs 8%, p<.0001). Overall, 60% of crashes occurred when there was no adverse weather; however, this was significantly more likely to be the case for vehicle-to-vehicle crashes than for single-vehicle (74% vs 48%, p<.0001).

Vehicle-to-vehicle crashes were more likely to happen during the week than single-vehicle crashes (79% vs 65%, p<.0001) with more on Friday than any other day. In addition, vehicle-to-vehicle crashes were significantly more likely to occur between 3pm and 6pm than single-vehicle crashes (36% versus 19%, p<.01). In contrast, single-vehicle crashes were more likely to occur on a weekend (35% vs 21%, p<.0001) and nearly three times more likely to occur between 9pm and midnight (14% vs 5%, p<.0001).

Table 9. Characteristics of roadway and environment by crash type.

	Single-vehicle (n=964)	Vehicle-to-vehicle (n=727)	Total (n=1691)
Road type[1]			
Interstate	54 (5.6%)	46 (6.3%)	100 (5.9%)
Arterial	75 (7.8%)	338 (46.5%)	413 (24.4%)
Collector	634 (65.8%)	252 (34.7%)	886 (52.4%)
Local	148 (15.4%)	49 (6.7%)	197 (11.7%)
All other	53 (5.5%)	42 (5.8%)	95 (5.6%)
Weather[1]			
No adverse weather	464 (48.1%)	540 (74.3%)	1004 (59.4%)
Fog	4 (0.4%)	3 (0.4%)	7 (0.4%)
Rain	44 (4.6%)	52 (7.2%)	96 (5.7%)
Sleet, hail, freezing rain	23 (2.4%)	4 (0.6%)	27 (1.6%)
Snow	133 (13.8%)	23 (3.2%)	156 (9.2%)
Unknown	296 (30.7%)	105 (14.4%)	401 (23.7%)
Surface condition[1]			
Dry	178 (18.5%)	571 (78.5%)	749 (44.3%)
Gravel	91 (9.44%)	2 (0.3%)	93 (5.5%)
Snow/ice	623 (64.6%)	60 (8.3%)	683 (40.4%)
Wet	65 (6.7%)	90 (12.4%)	155 (9.2%)
Other/unknown	7 (0.7%)	4 (0.6%)	11 (0.7%)
Time of day[1]			
Midnight to 3am	16 (1.7%)	3 (0.4%)	19 (1.1%)
3am to 5:59am	20 (2.1%)	3 (0.4%)	23 (1.4%)
6am to 8:59am	189 (19.6%)	124 (17.1%)	313 (18.5%)
9am to 11:59am	123 (12.8%)	66 (9.1%)	189 (11.2%)
Noon to 2:59pm	141 (14.6%)	140 (19.3%)	281 (16.6%)
3pm to 5:59pm	183 (19.0%)	259 (35.6%)	442 (26.1%)
6pm to 8:59pm	161 (16.7%)	93 (12.8%)	254 (15.0%)
9pm to 11:59pm	131 (13.6%)	39 (5.4%)	170 (10.1%)
Day of week[1]			
Monday	147 (15.3%)	98 (13.5%)	245 (14.5%)
Tuesday	136 (14.1%)	130 (17.9%)	266 (15.7%)
Wednesday	121 (12.6%)	113 (15.5%)	234 (13.8%)
Thursday	145 (15.0%)	117 (16.1%)	262 (15.5%)
Friday	145 (15.0%)	158 (21.7%)	303 (17.9%)
Saturday	152 (15.8%)	64 (8.8%)	216 (12.8%)
Sunday	118 (12.2%)	47 (6.5%)	165 (9.8%)
On a weekend (Fri 5pm to Sun 11:59pm)[1]			
Yes	336 (34.9%)	154 (21.2%)	490 (29.0%)
No	628 (65.2%)	573 (78.8%)	1201 (71.0%)
Light condition[1]			
Daylight	340 (35.3%)	468 (64.4%)	808 (47.8%)
Degraded daylight	236 (24.5%)	94 (12.9%)	330 (19.5%)
Dusk/dawn	65 (6.7%)	47 (6.5%)	112 (6.6%)
Dark, but lighted	131 (13.6%)	103 (14.2%)	234 (13.8%)
Dark, not lighted	192 (19.9%)	15 (2.1%)	207 (12.2%)

[1]p<.0001, [2]p<.01, [3]p<.05

Characteristics of crashes

Recognition and decision errors were the most common errors made by young drivers, occurring in 70% and 66% of all crashes, respectively. However, when examined by crash type (Table 10), recognition errors were significantly more common in vehicle-to-vehicle crashes than in single-vehicle crashes (89% vs 56%, p<.0001). In addition, both performance errors and decision errors were significantly more frequent in single-vehicle crashes (82% vs 9%, p<.0001, and 80% vs 47%, p<.0001, respectively).

Table 10. Type and frequency of young driver errors by crash type.

Error Type	Description	Single-vehicle (n=964)	Vehicle-to-vehicle (n=727)	Total (n=1691)
Recognition Errors	Any recognition errors[1] Inadequate Surveillance[1] Inattentive/Engaged in extraneous behaviors[1]	541 (56.1%) 242 (25.1%) 512 (53.1%)	643 (88.5%) 558 (76.8%) 475 (65.3%)	1184 (70%)
Decision Errors	Any decision errors[1] Driving too fast[1] Followed too closely[1] Ran stop sign/traffic signal[1] Travelling wrong way Unsafe lane change[3] Made improper turn Operating in a reckless manner[1] Failed to yield right of way (ROW)[1] Other illegal maneuver[2]	773 (80.2%) 764 (79.3%) 26 (2.7%) 10 (1.0%) 4 (0.4%) 1 (0.1%) 4 (0.4%) 30 (3.1%) 0 0	339 (46.6%) 12 (1.7%) 152 (20.9%) 66 (9.1%) 3 (0.4%) 6 (0.8%) 5 (0.7%) 2 (0.3%) 126 (17.3%) 6 (0.8%)	1112 (65.8%)
Performance Errors	Any performance errors[1] Lost control[1] Overcorrecting/over steering[1] Crossed centerline[2]	794 (82.4%) 793 (82.3%) 164 (17.0%) 0	63 (8.7%) 56 (7.7%) 2 (0.3%) 8 (1.1%)	857 (50.7%)
Non-performance Errors	Any non-performance errors Tired/falling asleep	12 (1.2%) 12 (1.2%)	3 (0.4%) 3 (0.4%)	15 (0.9%)

[1]p<.0001, [2]p<.01, [3]p<.05

Characteristics of vehicle-to-vehicle crashes

The majority of the vehicle-to-vehicle crashes coded were rear-end (57%) and angle crashes (40%). Other vehicle-to-vehicle crashes coded included, backing (2%), sideswipe (1%) and head-on (1%). In 8% of crashes, the critical precipitating event was a loss of control, most frequently due to environmental factors such as snowy/icy road conditions (Table 10). Eighty-eight percent of rear-end crashes involved another vehicle in the driver's lane decelerating or stopping on the roadway. Meanwhile, in 58% of angle crashes the participant vehicle was crossing the centerline or turning at an intersection, while in 38% another vehicle encroached into the participant's lane.

In 94% of vehicle-to-vehicle crashes the driver contributed to the crash in some way. However, note that this proportion is inflated due to the removal from the database of rear-end collisions in which the study participant's vehicle was struck from behind. The most common contributing factors were inadequate surveillance (76.8%), distraction/inattention (65.3%), following too closely (20.9%), and failure to yield right-of-way (ROW) (17.3%). The 727 vehicle-to-vehicle crashes included 1,481 driver errors, as it was possible for a crash to involve more than one error. Recognition errors, such as inadequate surveillance or distraction accounted for 70% of driver errors and occurred in 88% of the crashes. Decision errors, such as following too closely and running stop signs or lights accounted for 26% of total errors and occurred in 47% of crashes. Performance errors, such as losing control of the vehicle accounted for 5% of errors and occurred in 9% of crashes (see Table 10).

Table 11 shows the breakdown of driver errors by the two major types of vehicle-to-vehicle crashes (i.e., rear-end and angle), which together accounted for 97 percent of the vehicle-to-vehicle crashes. Rear-end crashes (n=412) had one or more recognition errors coded 93% of the time, decision errors 38% of the time, and performance errors 11% of the time. Angle crashes (n=290) had recognition errors coded 82% of the time, decision errors 61% of the time and performance errors 5% of the time. Decision errors such as a failure to yield ROW from a stop or when making a left turn and running stop signs/signals were significantly more frequent in angle crashes than in rear-end crashes (61% vs 38%, $p<.0001$). Recognition errors such as inadequate surveillance and inattention were more frequent in rear-end crashes than angle crashes (93% vs 82%, $p<.0001$). Performance errors such as losing control of the vehicle were also more common in rear-end crashes than angle crashes (11% vs 5%, $p<.01$)

Table 11. Type and frequency of young driver errors made in vehicle-to-vehicle crashes

Error Type	Description	Rear-end (n=412)	Angle (n=290)
Recognition Errors	Any recognition errors[1]	385 (93.4%)	237 (81.7%)
	Inadequate Surveillance[1]	367 (89.1%)	175 (60.3%)
	Inattentive/Engaged in extraneous behaviors[1]	313 (76.0%)	148 (51.0%)
Decision Errors	Any decision errors[1]	156 (37.9%)	178 (61.4%)
	Driving too fast	5 (1.2%)	5 (1.7%)
	Failed to yield ROW - At uncontrolled intersection[1]	0	8 (2.8%)
	Failed to yield ROW - Entering roadway[1]	0	11 (3.8%)
	Failed to yield ROW - From driveway	0	1 (0.3%)
	Failed to yield ROW - From stop sign[1]	0	53 (18.3%)
	Failed to yield ROW - Making left turn[1]	0	52 (17.9%)
	Failed to yield ROW - Right on red	0	1 (0.3%)
	Followed too closely[1]	148 (35.9%)	4 (1.4%)
	Misjudged gap	1 (0.2%)	0
	Operating in a reckless manner	2 (0.5%)	0
	Other illegal maneuver[2]	0	6 (2.1%)
	Ran stop sign/traffic signal[1]	0	66 (22.8%)
	Travelling wrong way	0	2 (0.7%)
	Unsafe lane change	4 (1.0%)	0
	Made improper turn[3]	0	6 (2.1%)
Performance Errors	Any performance errors[2]	45 (10.9%)	15 (5.2%)
	Crossed centerline	1 (0.2%)	4 (1.4%)
	Lost control[2]	44 (10.7%)	12 (4.1%)
	Overcorrecting/over steering	0	2 (0.7%)
Non-performance Errors	Any non-performance errors	3 (0.7%)	0
	Tired/falling asleep	3 (0.7%)	0

[1]p<.0001, [2]p<.01, [3]p<.05

Characteristics of single-vehicle crashes

Of the single-vehicle crashes coded, 66% were loss-of-control (LOC) crashes due to road surface or weather conditions, combined with travelling too fast for the conditions; 20% were road-departure crashes attributed to driver inattention due to distraction or inadequate surveillance; 12% were LOC crashes attributed to excessive speed; and 3% were LOC due to an evasive maneuver. Only one crash was attributed to LOC due to mechanical failure, a brake failure in this case.

Regardless of fault, in all but one of the crashes (99%) the driver contributed to the crash in some way. The 964 crashes included 2,562 driver errors (Table 10). The most common error type was performance error, including loss of control of the vehicle and overcorrecting/oversteering, observed in 82% of all crashes and accounting for 37% of

errors. Decision errors, such as running stop signs, driving too fast for conditions and, to a lesser extent, following too closely, were observed in 80% of crashes and accounted for 33% of errors. Meanwhile, recognition errors, such as inadequate surveillance and distraction occurred in 56% of crashes, accounting for 29% of the total number of driver errors.

Table 12 shows a breakdown of errors by the two major types of single-vehicle crashes (i.e., single vehicle LOC and road-departure). Recognition errors (i.e., inadequate surveillance or inattention) were present in 100% of road-departure crashes compared to only 46% of LOC crashes (p<.0001). Decision errors such as driving too fast for conditions and following too closely were more common in LOC crashes than in road-departure crashes (99% vs 4%, p<.0001). And, performance errors such as losing control of the vehicle and overcorrecting/oversteering were also more common in LOC crashes, present nearly 100% of the time, compared to only 12% of road-departure crashes (p<.0001).

Table 12. Type and frequency of young driver errors made in single-vehicle crashes

Error Type	Description	LOC (n=776)	Road-departure (n=188)
Recognition Errors	Any recognition errors[1]	353 (45.5%)	188 (100%)
	Inadequate Surveillance[1]	63 (8.1%)	179 (95.2%)
	Inattentive/Engaged in extraneous behaviors[1]	344 (44.3%)	168 (89.4%)
Decision Errors	Any decision errors[1]	766 (98.7%)	7 (3.7%)
	Driving too fast[1]	764 (98.5%)	0
	Followed too closely[1]	22 (2.8%)	4 (2.1%)
	Ran stop sign or signal	8 (1.0%)	2(1.1%)
	Travelling wrong way	4 (0.5%)	0
	Unsafe lane change	1 (0.1%)	0
	Made improper turn	3 (0.4%)	1 (0.5%)
	Operating in a reckless manner[3]	29 (3.7%)	1 (0.5%)
	Swerved to avoid object[2]	28 (3.6%)	0
Performance Errors	Any performance errors[1]	773 (99.6%)	21 (11.2%)
	Lost control[1]	772 (99.5%)	21 (11.2%)
	Overcorrecting/over steering[2]	144 (18.6%)	20 (10.6%)
Non-performance Errors	Any non-performance errors	5 (0.6%)	7 (3.7%)
	Tired/falling asleep[2]	5 (0.6%)	7 (3.7%)

[1]p<.0001, [2]p<.01, [3]p<.05

Driver behaviors

Analysts made no judgments as to whether the driver was actually distracted by any behavior observed, but simply coded what was occurring inside the vehicle at the time of the crash. In addition, multiple behaviors were sometimes observed in one crash event.

The proportion of crashes that involved potentially distracting driver behaviors was broken down by the major types of vehicle-to-vehicle and single-vehicles crashes as well as by gender (Table 13). Overall, drivers were seen engaging in some type of potentially distracting behavior leading up to 58% of the crashes. The two most frequently seen driver behaviors were attending to passengers (14.9%) and cell phone use (11.9%). Cell phone use

was significantly more likely in road-departure crashes than any other type of crash (34% vs 9.2%, p<.0001). Additionally, attending to a passenger was slightly less likely to be seen during a road-departure crash than any other crash types (13.3% vs 15.0%, p<.0001) (Figure 3). Overall, females were not more likely than males to be engaged in potentially distracting behavior. However, they were more likely than males to use a cell phone (14% vs 10%, p<.01), engage in personal grooming (7% vs 5%, p<.05), or sing/dance to music (9% vs 6%, p<.05).
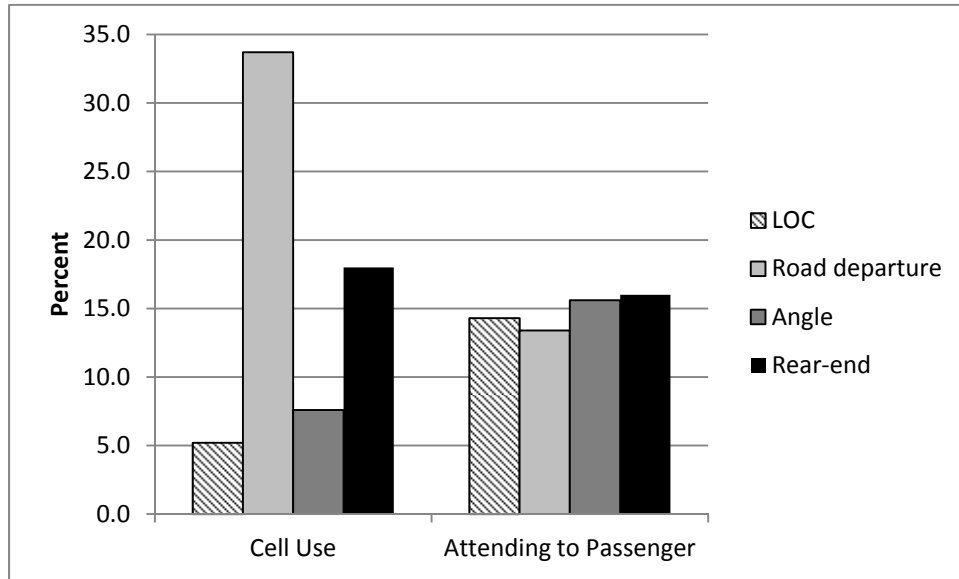

Figure 3. Most common driver behaviors by crash type

Table 13. Prevalence of driver behaviors by crash type

	Single-Vehicle						Vehicle-to-Vehicle						All Crashes		
	LOC (n=776)			Road-departure (n=188)[a]			Rear-end (N=412)			Angle (N=290)[a]			Total (N=1688)[b]		
	Total	Males (n=439)	Females (n=337)	Total	Males (n=99)	Females (n=88)	Total	Males (n=199)	Females (n=213)	Total	Males (n=164)	Females (n=125)	Total	Males (n=875)	Females (n=813)
							n (column %)								
Any behaviors	344 (44.3)	190 (43.3)	154 (45.7)	167 (89.3)	87 (87.9)	80 (90.9)	314 (76.2)	150 (75.4)	164 (77.0)	148 (51.2)	63 (50.4)	85 (51.8)	987 (58.5)	498 (56.9)	489 (60.2)
Any cell phone use	40 (5.2)	17 (3.9)	23 (6.8)	63 (33.7)	33 (33.3)	30 (34.1)	74 (18.0)	30 (15.1)	44 (20.7)	22 (7.6)	8 (6.4)	14 (8.5)	201 (11.9)	89 (10.2)	112 (13.8)[2]
Operating/looking	5 (0.6)	4 (0.9)	1 (0.3)	30 (16.0)	14 (14.1)	16 (18.2)	39 (9.5)	16 (8.0)	23 (10.8)	5 (1.7)	2 (1.2)	3 (2.4)	79 (4.7)	36 (4.1)	43 (5.3)
Talking/listening	32 (4.1)	14 (3.2)	18 (5.3)	9 (4.8)	4 (4.0)	5 (5.7)	4 (1.0)	1 (0.5)	3 (1.4)	12 (4.1)	5 (3.0)	7 (5.6)	57 (3.4)	24 (2.7)	33 (4.1)
Cell use likely but not visible	4 (0.5)	0	4 (1.2)	24 (12.8)	15 (15.2)	9 (10.2)	31 (7.5)	13 (6.5)	18 (8.5)	6 (2.1)	1 (0.6)	5 (4.0)	65 (3.9)	29 (3.3)	36 (4.4)
Eating or drinking	5 (0.6)	2 (0.5)	3 (0.9)	5 (2.7)	1 (1.0)	4 (4.6)	10 (2.4)	4 (2.0)	6 (2.8)	8 (2.8)	3 (2.4)	5 (3.1)	29 (1.7)	11 (1.3)	18 (2.2)
Using electronic device (mp3, iPod, nav)	0	0	0	1 (0.5)	1 (1.0)		7 (1.7)	4 (2.0)	3 (1.4)	3 (1.0)	3 (2.4)		11 (0.7)	8 (0.9)	3 (0.4)
Attending to a moving object inside vehicle	2 (0.3)	1 (0.2)	1 (0.3)	3 (1.6)	1 (1.0)	2 (2.3)	0	0	0	1 (0.4)	0	1 (0.6)	6 (0.4)	2 (0.2)	6 (0.7)
Attending inside vehicle, unknown	62 (8.0)	37 (8.4)	25 (7.4)	58 (31.0)	29 (29.3)	29 (33.0)	38 (9.2)	17 (8.5)	21 (9.9)	12 (4.2)	8 (6.4)	4 (2.4)	172 (10.2)	92 (10.5)	80 (9.8)
Attending to another vehicle or px in other vehicle	12 (1.6)	9 (2.1)	3 (0.9)	2 (1.1)	1 (1.0)	1 (1.1)	47 (11.4)	21 (10.6)	26 (12.2)	12 (4.2)	10 (8.0)[2]	2 (1.2)	75 (4.4)	42 (4.8)	33 (4.1)
Attending outside vehicle, unknown	41 (5.3)	27 (4.2)	27 (6.2)	20 (10.7)	11 (11.1)	9 (10.2)	71 (17.2)	34 (17.1)	37 (17.4)	17 (5.9)	7 (5.6)	10 (6.1)	151 (9.0)	80 (9.1)	71 (8.7)
Attending to passenger(s)	111 (14.3)	68 (15.5)[3]	43 (12.8)	25 (13.4)	13 (13.1)	12 (13.6)	66 (16.0)	36 (18.1)	30 (14.1)	45 (15.6)	16 (12.8)	29 (17.7)	251 (14.9)	136 (15.5)	115 (14.2)
Personal grooming	32 (4.1)	15 (3.4)	17 (5.0)	16 (8.6)	5 (5.1)	11 (12.5)	31 (7.5)	14 (7.0)	17 (8.0)	14 (4.8)	5 (4.0)	9 (5.5)	93 (5.5)	39 (4.5)	54 (6.6)[3]
Reaching for	14 (1.8)	5 (1.1)	9 (2.7)	46 (24.6)	26 (26.3)	20 (22.7)	25 (6.1)	9 (4.5)	16 (7.5)	9 (3.1)	3 (2.4)	6 (3.7)	95 (5.6)	44 (5.0)	51 (6.3)

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	Single-Vehicle						Vehicle-to-Vehicle						All Crashes		
	LOC (n=776)			Road-departure (n=188)[a]			Rear-end (N=412)			Angle (N=290)[a]			Total (N=1688)[b]		
	Total	Males (n=439)	Females (n=337)	Total	Males (n=99)	Females (n=88)	Total	Males (n=199)	Females (n=213)	Total	Males (n=164)	Females (n=125)	Total	Males (n=875)	Females (n=813)
							n (column %)								
object															
Singing/Dancing to music	64 (8.3)	28 (6.4)	36 (10.7)[3]	7 (3.7)	4 (4.0)	3 (3.4)	39 (9.5)	16 (8.0)	23 (10.8)	19 (6.6)	8 (6.4)	11 (6.7)	130 (7.7)	56 (6.4)	74 (9.1)[3]
Smoking related	4 (0.5)	1 (0.2)	3 (0.9)	7 (3.7)	4 (4.0)	3 (3.4)	4 (1.0)	3 (1.5)	1 (0.5)	4 (1.4)	3 (2.4)	1 (0.6)	19 (1.1)	11 (1.3)	8 (1.0)
Talking to self	17 (2.2)	12 (2.7)	5 (1.5)	5 (2.7)	1 (1.0)	4 (4.6)	5 (1.2)	2 (1.0)	3 (1.4)	9 (3.1)	4 (3.2)	5 (3.1)	36 (2.1)	19 (2.2)	17 (2.1)
Operating in-vehicle controls/devices	11 (1.4)	5 (1.1)	6 (1.8)	15 (8.0)	9 (9.1)	6 (6.8)	18 (4.4)	10 (5.0)	8 (3.8)	8 (2.8)	2 (1.6)	6 (3.7)	55 (3.3)	28 (3.2)	27 (3.3)
Attending elsewhere, unknown	6 (0.8)	2 (0.5)	4 (1.2)	1 (0.5)	0	1 (1.1)	1 (0.2)	0	1 (0.5)	0	0	0	8 (0.5)	92 (10.5)	80 (9.8)
Attending to person outside vehicle	0	0	0	0	0	0	7 (1.7)	4 (2.0)	3 (1.4)	1 (0.4)	0	1 (0.6)	9 (0.5)	5 (0.6)	4 (0.5)

[1]p<.0001, [2]p<.01, [3] p<.05, [a]The male and female totals do not equal the number of crashes due to sex being unknown in 1 road-departure and 1 angle crash. [b]This total does not equal the total of LOC, Road departure, Rear-end and Angle as it includes "other vehicle-to-vehicle" crash types

Driver behaviors present in vehicle-to-vehicle crashes

In two-thirds of all vehicle-to-vehicle crashes (65%, n=476) there were potentially distracting driver behaviors. A total of 646 behaviors were coded in these 476 crashes. Type and frequency of behaviors observed are shown in Figure 4. There were no statistically significant differences between the types and frequencies of behaviors by gender.
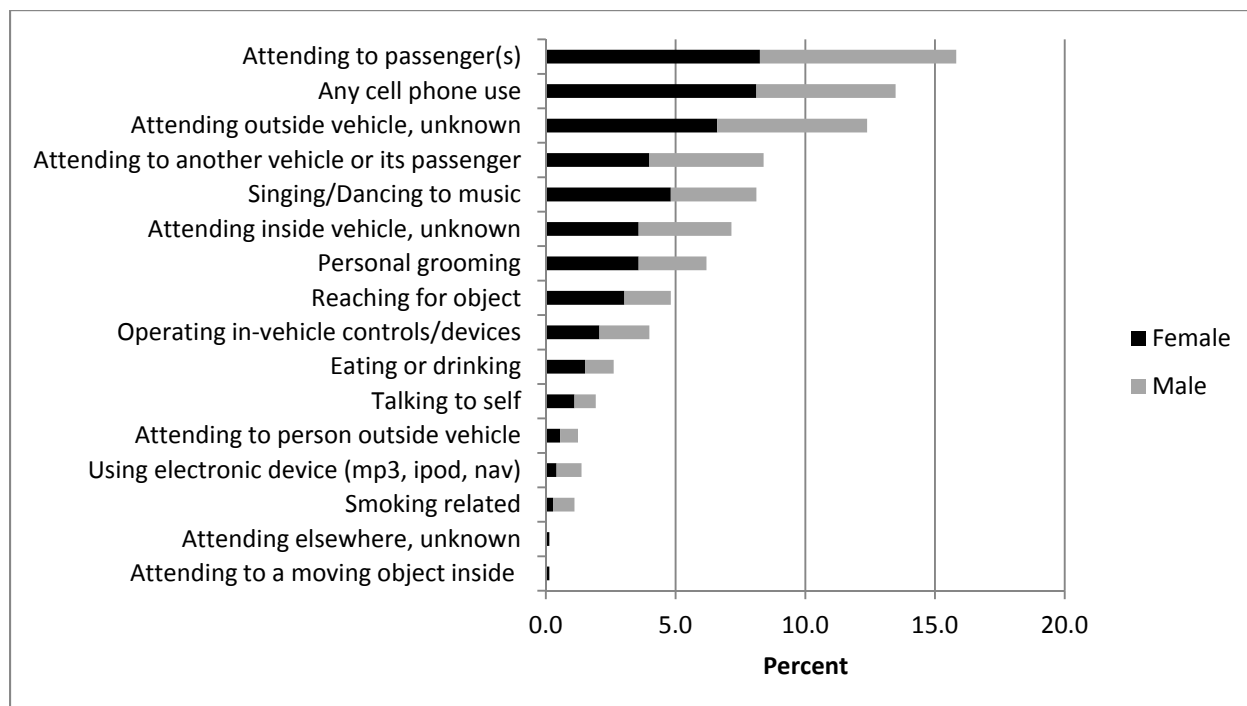

Figure 4. Percent of vehicle-to-vehicle crashes containing driver behaviors by gender

Among all vehicle-to-vehicle crashes, attending to passengers was the most frequently seen driver behavior, present in 15.8% of all crashes. Among crashes with passengers present in the vehicle (n=283), 40.6% involved the driver attending to them. Cell phone use was the second most frequent driver behavior, observed in 13.5% of all vehicle-to-vehicle crashes. Among all cell phone-related events (n=98), the driver was coded as operating or looking at the phone in 45.9% (n=45) of such events, talking/listening in 16% (n=16) with one driver talking on a hands-free phone, and cell phone use was coded as likely but not visible in 38.8% (n=38). The relative frequency of these types of behaviors did not differ by gender. Attending outside the vehicle to an unknown location was the third most common driver behavior. It was coded in 12.4% of crashes.

Overall, drivers were seen engaging in non-driving activities in the 6 seconds leading up to the crash in 65% of all vehicle-to-vehicle crashes examined. However, when broken down by crash type, as shown in Figure 5, three out of four (76.2%) rear-end crashes involved a driver engaging in a non-driving activity, while just over half (51.2%) of angle crashes involved such an activity (p<.0001).
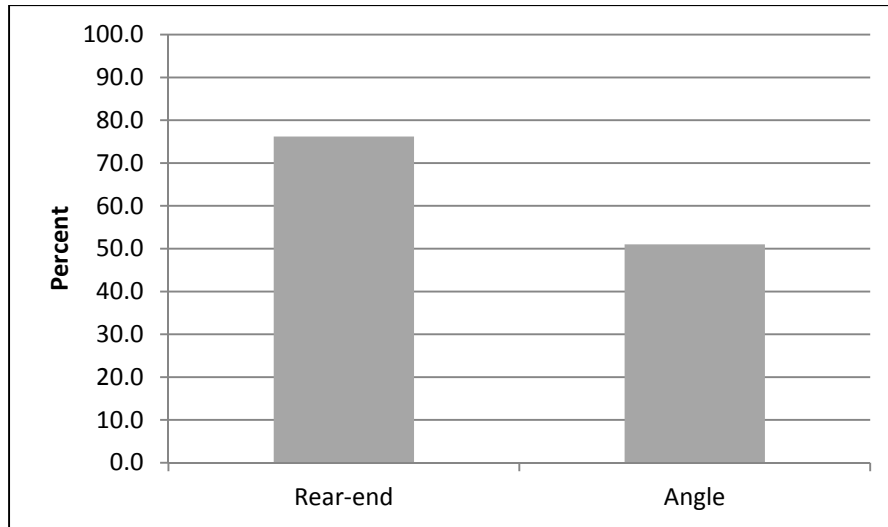
Figure 5. Percent of vehicle-to-vehicle crashes with potentially distracting
driver behavior by crash type

The most frequently occurring potentially distracting driver behaviors were examined for
vehicle-to-vehicle crash type (Figure 6). Rear-end crashes were significantly more likely
than angle crashes to involve the driver using a cell phone (18.0% vs 7.6%, respectively
$p<.0001$). Drivers attending outside the vehicle to an unknown location were also seen
significantly more often in rear-end crashes than in angle crashes (17.2% vs 5.9%, $p<.0001$).
There was no significant difference, however, with respect to the types of crashes in which
drivers were seen interacting with passengers. Rear-end crashes and angle crashes were
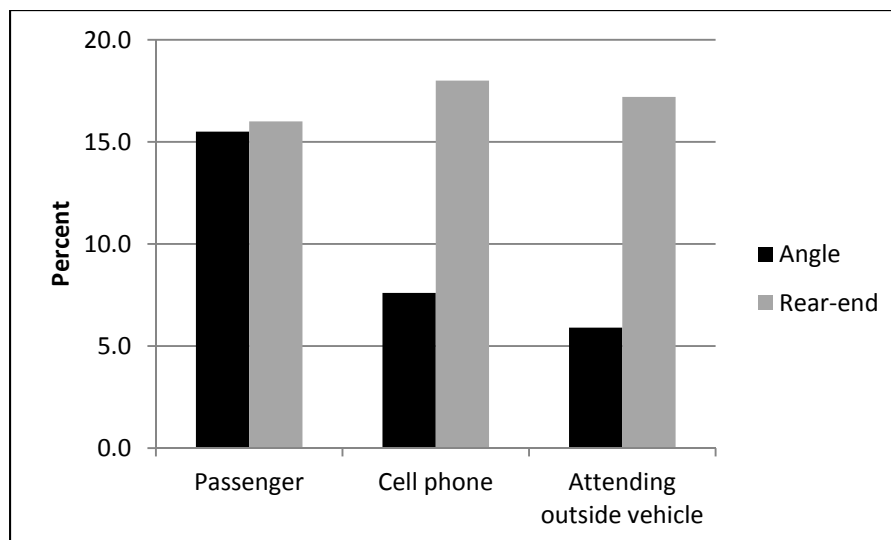equally likely to have drivers attending to a passenger (16% and 15.6%, respectively).

Figure 6. Three most common driver behaviors by vehicle-to-vehicle crash type

Additionally, driver behaviors were examined by the number of passengers present in the vehicle. Potentially distracting driver behaviors were present in 61% of vehicle-to-vehicle crashes where the driver was in the vehicle alone, 70% of crashes where one passenger was present, and 78% of crashes where there were two or more passengers (p=0.0028). Drivers were significantly more likely to be using their cell phone (17.3% vs. 7.4%, p=.0001) or attending to something outside the vehicle (15.3% vs 7.8%, p=0.0026) when they were alone; when passengers were present, they were more likely to be attending to another vehicle or a person in another vehicle (11.3% vs 6.5%, p=0.0235).

Driver behaviors present in single-vehicle crashes

Potentially distracting driver behaviors were observed in slightly more than half of single-vehicle crashes (53.1%, n=512). A total of 698 behaviors were coded in these 512 crashes. The type and frequency of behaviors observed are shown in Figure 7. Overall, there was no significant difference in the presence of potentially distracting driver behaviors by gender (55.0% females and 51.5% males, p=0.27); however, the prevalence of some specific potentially-distracting behaviors varied by gender. For example, females were more likely than males to be using their cell phone (12.5% vs 9.3%, p=0.11), performing personal grooming (6.6% vs. 3.7%, p=0.04), and dancing or singing (9.2% vs 6.0%, p=0.06).

Attending to a passenger was the most frequently observed driver behavior in single-vehicle crashes and was observed in 14.1% of crashes. Among single-vehicle crashes in which a passenger was present in the vehicle (n=325), 41.8% involved the driver attending to the passenger. Meanwhile, attending inside the vehicle to an unknown location was the second most frequent driver behavior, seen in 12.5% (120 of 964) of crashes. Cell phone-related behaviors were the third most frequently coded, occurring in 10.8% of single-vehicle crashes (n=104). The driver was coded as operating or looking at the phone in 35% (n=36) of the cell phone-related events (n=104), talking/listening in 39% (n=41) with one driver talking on a hands-free phone, and cell phone use was coded as likely but not visible in 27% (n=28).
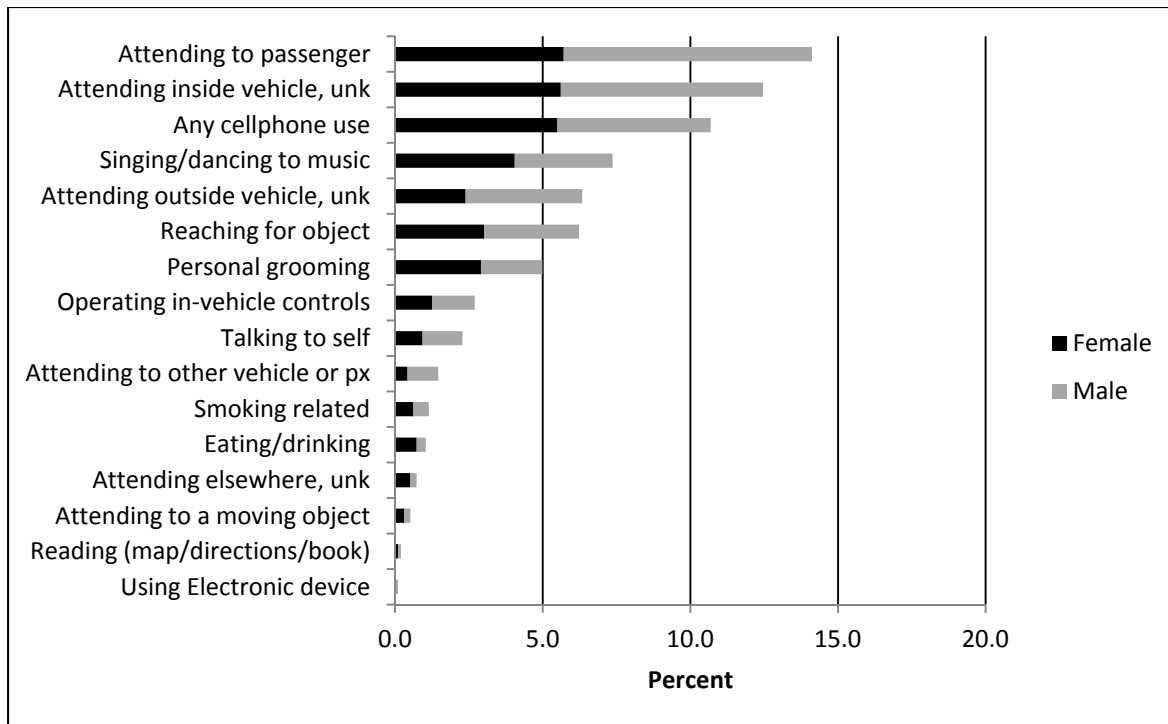
Figure 7. Percent of single-vehicle crashes containing driver behavior by gender

Overall, drivers were observed engaging in non-driving-related activities during the 6s before the crash in slightly more than half of single-vehicle crashes (53%). However, when broken down by crash type (Figure 8), drivers were substantially less likely to be engaged in distracting activities prior to any type of LOC crash than prior to road-departure crashes (44% vs 89.4%, respectively, p<.0001).
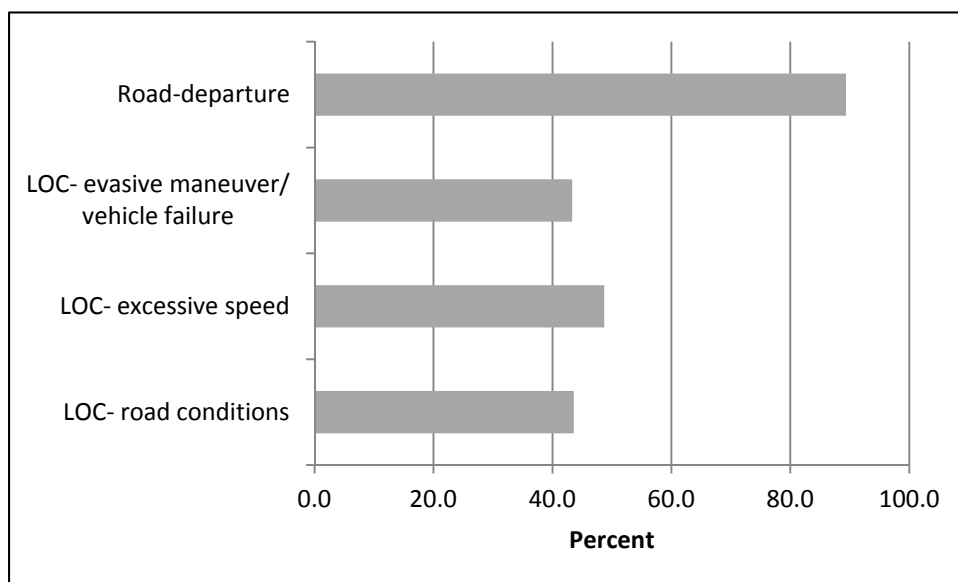

Figure 8. Percent of single-vehicle crashes with potentially distracting driver behavior by crash type

The most frequent potentially distracting driver behaviors were examined by single-vehicle crash type (Figure 9). Cell phone use was present in a significantly greater proportion of road-departure crashes than LOC crashes (33.7% vs 5.2%, p<.0001). Attending inside the vehicle to an unknown location was also seen significantly more frequently in road-departure crashes than in LOC crashes (31.0% vs 8.0%, p<.0001). Attending to passengers was similarly likely (14.3% vs 13.1%) in both LOC and road-departure crashes.
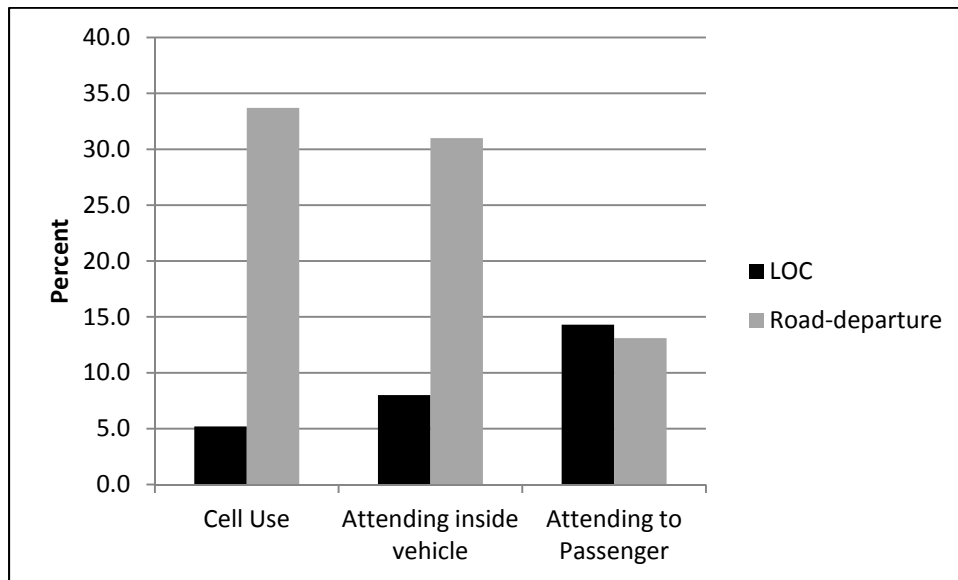

Figure 9. Three most common driver behaviors by single-vehicle crash type

Additionally, driver behaviors were examined by the number of passengers present in the vehicle. Potentially distracting driver behaviors were present in 48% of single-vehicle crashes where the driver was in the vehicle alone, 62% of crashes where one passenger was present, and 66% of those with two or more passengers (p<0.0001). Drivers were significantly more likely to use their cell phone when they were alone (13.3% vs 5.9%, p=0.0004), in particular operating/looking (4.7% vs 1.9%, p=0.0274), or to be attending to something inside the vehicle (14.2% vs 8.9%, p=0.0181). When passengers were present, drivers were more likely to be attending to a passenger (49.5%, 136 of 275) than engaging in any other behavior, with attending inside the vehicle to an unknown location a distant second (10.5%, 29 of 275).

Inadequate surveillance of the roadway

Road-departure and rear-end crashes had significantly higher proportions of crashes containing inadequate surveillance (95% and 89%, respectively) compared to 60% of angle crashes and only 8% of LOC crashes (p<.0001). LOC crashes were more likely than any other crash type to have a driver that was adequately surveying the roadway (Figure 10). This was particularly true for LOC crashes in which road conditions were a factor, during which drivers were seen adequately surveying the roadway 94% of the time.
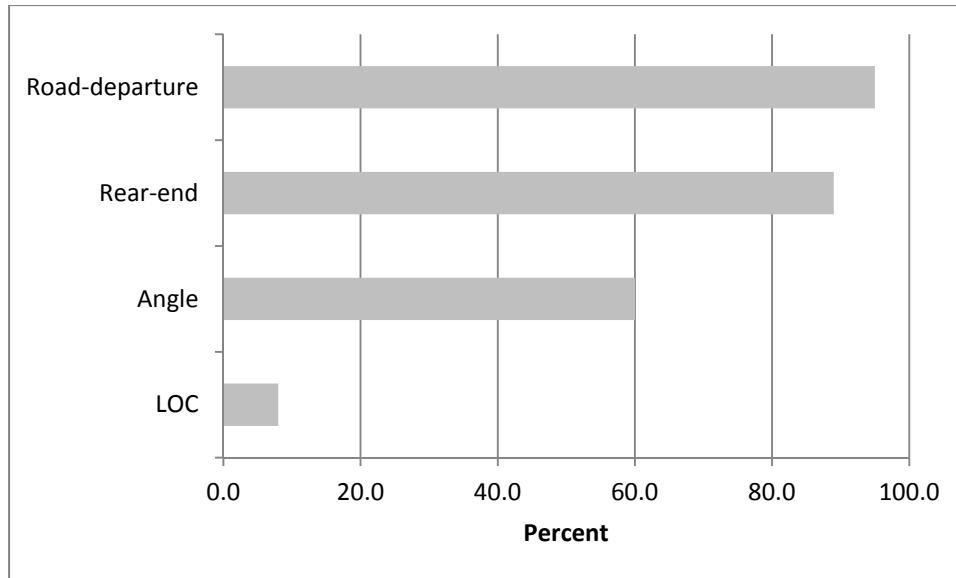
Figure 10. Percent of crashes involving inadequate surveillance by crash type

Eyes-off-road time

Related to inadequately surveying the roadway is the total amount of time the driver had their eyes off the forward roadway during the 6s preceding the crash. There was a large difference in the average time drivers' eyes were off of the road when examined by crash type (Table 14). Overall, drivers had significantly longer mean eyes-off-road time prior to road departure crashes than any other crash type (p<.0001). A comparison of vehicle-to-vehicle crashes found that drivers involved in rear-end crashes had their eyes off the roadway nearly 3.5 times as long as those involved in an angle crash (2.5s vs 0.7s, p<.0001). For single-vehicle crashes, drivers involved in roadway-departure crashes had their eyes off the road for nearly 4s on average, compared to just 0.5s for LOC crashes (p<.0001).

Table 14. Mean total eyes-off-road time in 6 seconds preceding crash, by crash type.

	Single-vehicle		Vehicle-to-vehicle		
	LOC (n=776)	Road-departure (n=188)	Rear-end (n=412)	Angle (n=290)	All (n=1688)
Mean (std dev)	0.5 (0.9)[1]	3.9 (1.6)	2.5 (1.9)[1]	0.7 (1.2)[1]	1.4 (1.8)
N (%) of crashes with eyes off the road for 6 seconds	1 (0.2)	6 (3.8)	5 (1.3)	0	12 (0.9)
N (%) of crashes with eyes off the road for 0 seconds	438 (70.9)	11 (7.0)	82 (21.9)	165 (66.0)	696 (49.7)

[1] p<.0001 compared to road departure

Of all driver behaviors, using electronic devices, attending to a moving object in the vehicle, using a cell phone and reaching for an object were associated with the longest mean eyes off

forward road times (3.9s, 3.6s, 3.3s and 3.3s, respectively [Table 15]). Drivers engaged in any cell use had mean eyes-off-road times that were twice as long as those drivers who were attending to passengers (3.3s vs 1.5s, p<.0001). Interestingly, when cell phone use was broken down, the average eyes-off-road time for drivers who were operating or looking at their phone was 4.1s, compared to 0.9s for drivers who were talking or listening.

Table 15. Mean eyes-off-road time in 6 seconds preceding crash, by crash type and driver behavior.

	Single-vehicle				Vehicle-to-vehicle				All crashes	
	LOC		Road-departure		Rear-end		Angle			
	N	Mean (std)[a]	N	Mean (std)[a]	N	Mean (std)[a]	N	Mean (std)[a]	N	Mean (std)[a]
No distractions	432	0.05 (0.3)	20	0.8 (1.5)	98	0.9 (1.6)	142	0.1 (0.5)	692	0.2 (0.8)
Any distraction	344	0.9 (1.1)[1]	168	4.2 (1.4)[1]	314	3.0 (1.7)[1]	148	1.2 (1.4)[1]	974	2.2 (1.9)[1]
Any cell phone use	40	0.8 (1.1)[1]	64	4.5 (1.1)[1]	74	4.0 (1.3)[1]	22	1.9 (1.7)[1]	200	3.3 (1.9)[2]
Operating/looking	5		31	4.7 (0.9)[1]	39	4.1 (1.3)[1]	5		80	4.1 (1.4)[1]
Talking/listening	32	0.4 (0.7)[3]	9		4		12	0.8 (1.2)	57	0.9 (1.5)[2]
Cell phone use likely but not visible	4		24	4.4 (1.0)[1]	31	4.0 (1.3)[1]	6		65	4.0 (1.2)[1]
Eating or drinking	5		5		10	2.5 (1.5)[2]	8		28	2.4 (1.9)[1]
Using electronic device (mp3, ipod, nav)	0		1		7		3		11	3.9 (1.1)[1]
Attending to a moving object inside vehicle	2		3		0		1		6	
Attending inside vehicle, unknown	62	1.5 (1.0)[1]	58	4.0 (1.4)[1]	38	2.8 (1.4)[1]	12	2.1 (1.0)[1]	170	2.7 (1.6)[1]
Attending to another vehicle or passenger in other vehicle	12	2.7 (1.6)[1]	2		47	3.1 (1.4)[1]	12	1.6 (1.0)[1]	73	2.8 (1.5)[1]
Attending outside vehicle, unknown	41	1.6 (0.9)[1]	20	3.9 (1.4)[1]	71	3.2 (1.4)[1]	17	2.4 (1.3)[1]	149	2.8 (1.5)[1]
Attending to passenger(s)	111	0.6 (1.1)[1]	25	3.8 (1.5)[1]	66	2.5 (1.8)[1]	45	0.9 (1.2)[1]	247	1.5 (1.8)[1]
Personal grooming	32	0.9 (1.2)[1]	16	3.0 (1.8)[2]	31	3.1 (2.0)[1]	14	0.9 (1.1)[2]	93	2.1 (1.9)[1]
Reaching for object	14	2.2 (1.5)[1]	46	4.2 (1.2)[1]	25	3.0 (1.3)[1]	9		94	3.3 (1.6)[1]
Singing/Dancing to music	64	0.7 (0.9)[1]	7		39	2.1 (1.7)[2]	19	0.6 (1.0)	129	1.4 (1.6)[1]
Smoking related	4		7		4		4		19	2.9 (2.1)[1]
Talking to self	17	0.4 (0.9)	5		5		9		36	1.0 (1.7)[2]
Operating in-vehicle controls/devices	11	1.6 (0.9)[1]	15	4.0 (1.3)[1]	18	2.6 (1.2)[2]	8		52	2.6 (1.6)[1]
Attending elsewhere, unknown	6		1		1	1.5	0		8	
Attending to person outside vehicle	0		0		7	2.6 (1.4)[2]	1		8	

[1]p<.0001, [2]p<.01, [3] p<.05 compared to eyes of the road for drivers with no distractions. [a] Means and standard deviations not shown for cells with N<10

Reaction Time

Reaction time was analyzed for rear-end crashes only, and then only when the lead vehicle was moving and brake lights were visible. Therefore, among rear-end crashes (n=412), a reaction time (including no reaction) was coded for 244 (59%) crashes. Drivers who were using a cell phone, attending outside the vehicle to an unknown location and operating in-vehicle controls all had significantly longer reaction times compared to drivers who were not engaged in potentially distracting behaviors (Table 16).

When reaction times were examined for the two most common potentially distracting driver behaviors, drivers using a cell phone had a significantly longer reaction time than drivers who were not engaged in any behaviors (2.8s vs 2.1s, p<.05), while those who were attending to passengers did not (2.2s vs 2.1s). In addition, over 50% of rear-end crashes in which the driver was engaged in cell-phone use showed no driver reaction (i.e., lack of braking or steering input) before impact (compared to 9.5% of crashes with a passenger driver distraction). In fact, a driver having no reaction was very rare when the driver was attending to passengers; drivers were actually more likely to fail to react at all when not engaged in any observable potentially distracting behavior than when attending to passengers (30% vs. 9.5%, p<.05).

Table 16. Reaction time for rear-end crashes by type of driver behavior

Driver Behavior	Reaction Time (N=180)		No Reaction (n=64)
	N (row %)	Mean (std)	N (row %)
No driver behavior	35 (70.0)	2.1 (1.2)	15 (30.0)
Any driver behavior	145 (74.7)	2.4 (1.0)	49 (25.3)
Any cell phone use	21 (48.8)	2.8 (0.9)[3]	22 (51.1)[1]
Use of cell phone (operating/ looking)	9 (47.4)	3.4 (1.0)[2]	10 (52.6)[2]
Use of cell phone (talking/ listening)	1 (33.3)	2.8	2 (66.7)
Cell phone use likely but not visible	11 (52.4)	2.4 (0.6)	10 (47.6)[3]
Eating or drinking	5 (83.3)	1.8 (0.7)	1 (16.7)
Using electronic device (mp3, ipod, nav)	2 (40.0)	3.5 (1.1)	3 (60.0)
Attending to a moving object inside vehicle[a]	0		0
Attending inside vehicle, unknown	16 (70.6)	2.1 (1.0)	7 (30.4)
Attending to another vehicle or px in other vehicle	26 (78.8)	2.3 (0.9)	7 (21.2)
Attending outside vehicle, unknown	38 (76.0)	2.6 (1.0)[3]	12 (24.0)
Attending to passenger(s)	38 (90.5)	2.2 (0.9)	4 (9.5)[3]
Personal grooming	13 (68.4)	2.2 (0.9)	6 (31.6)
Reaching for object	7 (58.3)	2.1 (0.4)	5 (41.7)
Singing/Dancing to music	20 (83.3)	2.4 (0.9)	4 (16.7)
Smoking related[a]	0		2 (100.0)
Talking to self	2 (66.7)	2.0 (0.4)	1 (33.3)
Operating in-vehicle controls/devices	8 (100.0)	3.0 (0.7)[3]	0
Attending elsewhere, unknown[a]	0		0
Attending to person outside vehicle	4 (100.0)	2.8 (1.2)	0

[1]p<.0001, [2]p<.01, [3] p<.05 compared to reaction time for drivers engaged in no potentially distracting behavior (means) or comparison of proportion with and without time to react, [a] these behaviors did not have reaction times

Passenger behaviors

Passengers were present in 36% of the crashes. The characteristics of the 864 passengers present in those crashes are shown in Table 17. A majority of passengers were estimated to be 16-19 years old (84%); 55% were male and 44% were female.

Table 17. Characteristics of passengers present in crashes.

Age	Vehicle-to-vehicle crashes (n=283)			Single-vehicle crashes (n=325)			TOTAL
	Male	Female	Total	Male	Female	Total	
	N (cell %)			N (Cell %)			N (Col %)
1-4	0	2 (0.4%)	2 (0.4%)	0	1 (0.2%)	2 (0.4%)	4 (0.5%)
5-10	5 (1.2%)	6 (1.5%)	11 (2.7%)	4 (0.9%)	5 (1.1%)	10 (2.2%)	21 (2.4%)
11-15	28 (6.9%)	10 (2.5%)	38 (9.3%)	31 (6.8%)	11 (2.4%)	42 (9.2%)	80 (9.3%)
16-19	169 (41.4%)	167 (40.9%)	337 (82.6%)	220 (48.2%)	165 (36.2%)	388 (85.1%)	725 (83.9%)
20-29	5 (1.2%)	0	5 (1.2%)	0	0	0	5 (0.6%)
30-64	5 (1.2%)	7 (1.7%)	12 (2.9%)	6 (1.3%)	8 (1.8%)	14 (3.1%)	26 (3.0%)
65+	1 (0.2%)	2 (0.4%)	3 (0.7%)	0	0	0	3 (0.3%)
Total[a,b]	213 (52.2%)	194 (47.5%)	408[a] (100%)	261 (57.2%)	190 (41.7%)	456[b] (100%)	864 (100%)

[a]There was one 16-19 year old passenger in the vehicle-to-vehicle crashes for which gender could not be determined.

[b]There was one 1-4 year old, one 5-10 year old and three 16-19 year old passengers in the single-vehicle crashes for which gender could not be determined.

Overall, the most frequent passenger behavior was conversation with the driver (Table 18). When a single passenger was present, they were engaged in conversation with the driver in 36% of crashes examined; when two or more passengers were present, they were engaged in conversation with the driver in 39% of crashes examined. When two or more passengers were present they were significantly more likely to be making loud noises (5% vs 0.2%, p<.01), moving around in the vehicle (14% vs 6%, p<.01) and texting/using cell phone (7% vs 3%, p<.01) than when only a single passenger was present.

Table 18. Passenger behaviors observed in relation to crash type and number of passengers, among crashes in which at least one passenger was present.

	Single-vehicle Crashes (n=325)		Vehicle-to-vehicle Crashes (n=274)		All Crashes with Passengers Present (n=608)[b]	
	1 Passenger (n=231)	2+ Passengers (n=94)	1 Passenger (n=194)	2+ Passengers (n=80)	1 Passenger (n=431)	2+ Passengers (n=177)
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
Any passenger behaviors	113 (48.9)	63 (67.0)[2]	104 (53.6)	59 (73.8)[2]	223 (51.7)	124 (70.1)[1]
Adjusting vehicle controls	3 (1.3)	2 (2.1)	9 (4.6)	0	12 (2.8)	2 (1.1)
Giving directions	4 (1.7)	1 (1.1)	6 (3.1)	3 (3.8)	10 (2.3)	4 (2.3)
Making loud noises	1 (0.4)	5 (5.3)	0	3 (3.8)	1 (0.2)	8 (4.5)[2]
Moving around in vehicle	15 (6.5)	6 (6.4)	8 (4.1)	18 (22.5)	25 (5.8)	25 (14.1)[2]
On the phone	3 (1.3)	1 (1.1)	5 (2.6)	3 (3.8)	8 (1.9)	4 (2.3)
Pointing something out	0	1 (1.1)	2 (1.0)	3 (3.8)	2 (0.5)	4 (2.3)
Purposely distracting driver	0	0	0	2 (2.5)	0	2 (1.1)
Reaching for dropped/spilled something	4 (1.7)	2 (2.1)	8 (4.1)	3 (3.8)	12 (2.8)	5 (2.8)
Singing	9 (3.9)	5 (5.3)	11 (5.7)	6 (7.5)	20 (4.6)	11 (6.2)
Smoking related	1 (0.4)	3 (3.2)	1 (0.5)	1 (1.3)	3 (0.7)	4 (2.3)
Engaged in conversation with driver	81 (35.1)	42 (44.7)	71 (36.6)	27 (33.8)	156 (36.2)	69 (39.0)
Engaged in conversation with other passenger(s)	--[a]	16 (17.0)	--[a]	24 (30.0)	--[a]	41 (23.2)
Texting/Using cell phone	6 (2.6)	6 (6.4)	5 (2.6)	7 (8.8)	11 (2.6)	13 (7.3)[2]
Yelling	6 (2.6)	5 (5.3)	2 (1.0)	2 (2.5)	8 (1.9)	7 (4.0)

[1]p<.0001, [2]p<.01, [3] p<.05,
[a]No comparison made as no other passenger available to talk with.
[b]This total includes "other vehicle-to-vehicle" crash types

Passenger behaviors present in vehicle-to-vehicle crashes

Passengers were present in only about one-third of all vehicle-to-vehicle crash events (39%, n=283). A single passenger was present in 28% of crashes, two passengers in 8% of crashes, and three or more passengers in 3% of crashes. A large majority of passengers were ages 16-19 (82.6%), and they were split evenly between male (52%) and female (48%).

Passenger behaviors observed in the vehicle during the 6s leading up to the crash are shown in Figure 11. When passengers were present at the time of the crash, the most frequent behavior they engaged in was conversation with the driver (36% of crashes). Moving around in the vehicle was seen in 10%, and talking with other passengers in 9% of crashes. Among crashes with one (n=200) or two (n=55) passenger(s), the most commonly reported behavior was talking with the driver (37.5% and 32.7%, respectively). Among crashes with 3 or more passengers (n=28), talking with another passenger and moving around in the vehicle each represented 35.7% of the passenger behaviors.

In contrast to the potentially distracting behaviors that passengers engaged in, passengers were seen alerting drivers to impending collisions by redirecting their attention to the forward roadway (e.g., using a sound or gesture) in 32% of vehicle-to-vehicle crashes.
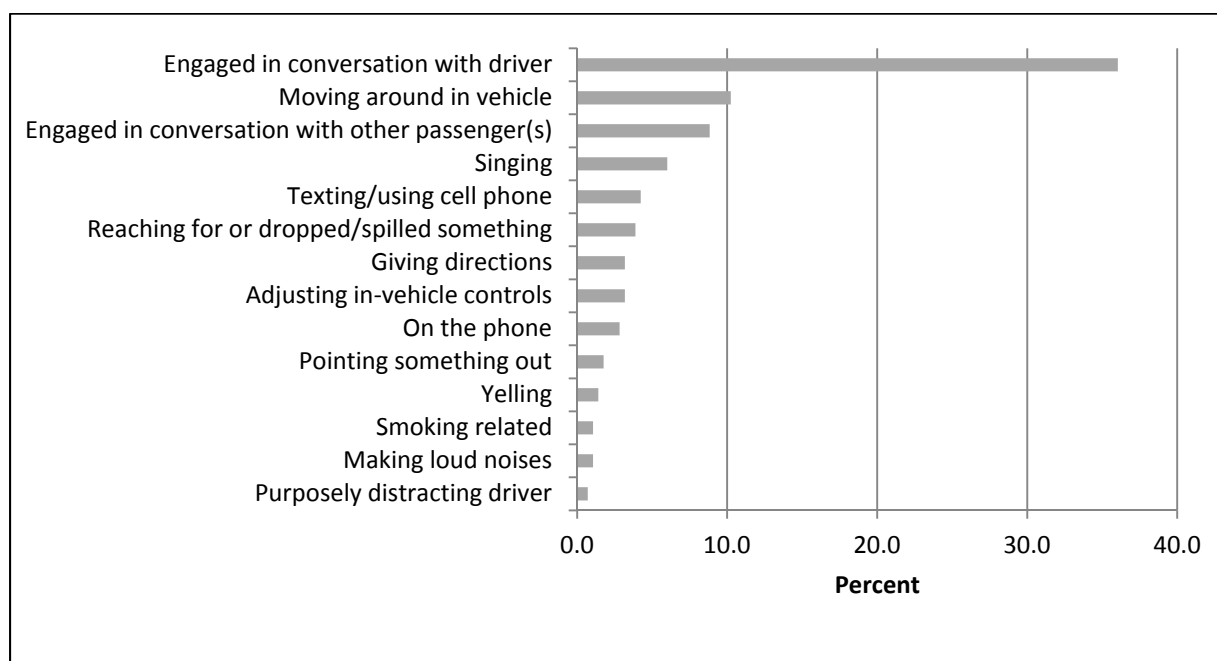

Figure 11. Passenger behaviors observed in vehicle-to-vehicle crashes with passengers present.

Passenger behaviors present in single-vehicle crashes

One-third of drivers (34%, n=325) involved in a single-vehicle crash were carrying passengers; one passenger was present in 24% of single-vehicle crashes, two passengers were present in 7%, and three or more were present in 3%. A large majority of the passengers were estimated to be 16-19 years old (86.5%); 57.2% were male.

The types of behaviors that passengers were engaged in during the 6s leading up to the crashes are shown in Figure 12. Conversation with the driver, observed in 38% of single-vehicle crashes with passengers present and accounting for 55% of all passenger behaviors observed in these crashes, was by far the most common passenger behavior. Less

commonly, passengers were seen moving around in the vehicle and talking with other passengers.

When there was only one passenger, he/she was as likely to be engaged in conversation with the driver (35%, 81 of 231 crashes with only 1 passenger) as when 2 or more passengers were present (45%, 42 of 94 crashes with two or more passengers).

In contrast to the potentially distracting behaviors by passengers, passengers were seen alerting drivers to impending collisions by redirecting their attention to the forward roadway (e.g., using a sound or gesture) in 9% of single-vehicle crashes.
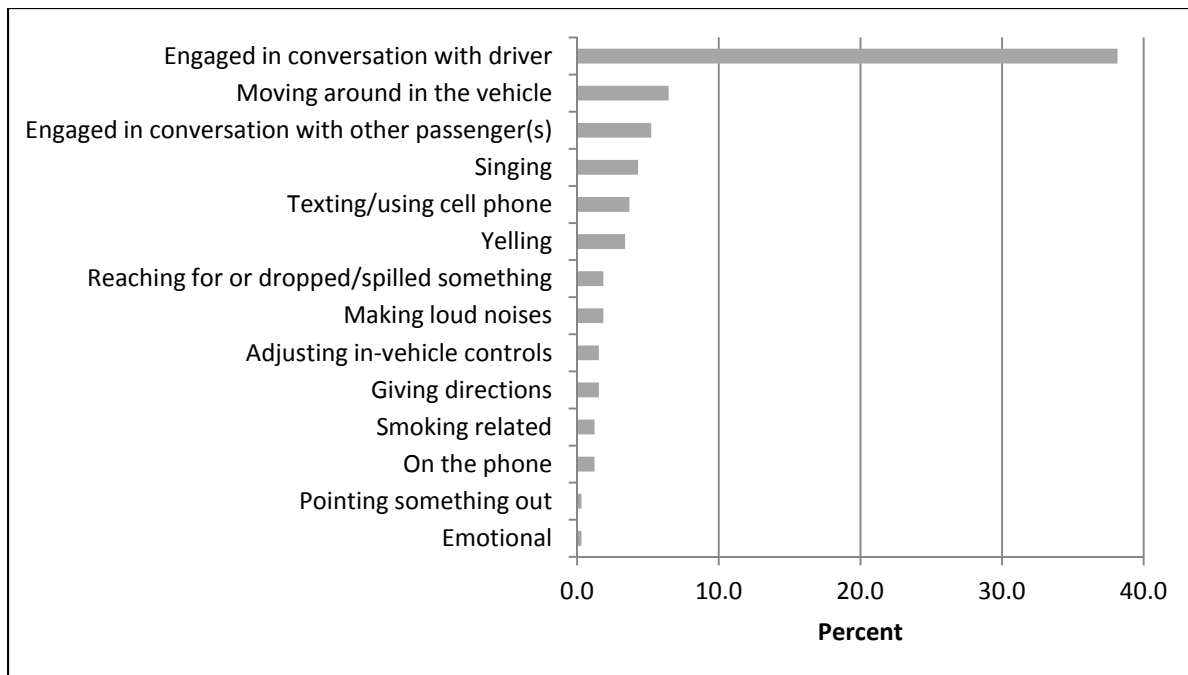

Figure 16. Among single-vehicle crashes with passengers, percent and type of passenger behaviors

Drowsy driving

Driver fatigue was identified as a contributing cause in only three of the 727 vehicle-to-vehicle crashes and 12 of the 964 single-vehicle crashes. This was less than 1% of the total crashes reviewed. Several possible explanations for this unusual result will be discussed in the next section.

Discussion

This project is the first large-scale examination of naturalistic crash data involving young drivers. Other naturalistic studies have recorded a much smaller number of crashes, necessitating reliance on near-crashes as a surrogate for crashes. This study analyzed nearly 1,700 crashes involving young drivers. In the past, this large of a number of crashes could have only been analyzed from police reports. While police reports are useful, they have numerous limitations—such as reliance on driver and/or eyewitness testimony. Not only do naturalistic data give us the ability to examine the behaviors and actions of drivers and passengers in the seconds leading up to a crash, they also allow us to study crashes at the micro level, examining factors such as eye glances and reaction times. This kind of analysis clearly is not possible with datasets that rely on police reports.

A naturalistic driving database of over 6,800 crashes was reviewed for this study. Moderate-to-severe crashes (e.g., those with an impact >1.0g) were identified for inclusion in the analysis. A coding methodology was developed that was specific to capturing information relevant to crash causation, and that concentrated on driver behaviors/actions present in the vehicle. The following research questions were addressed:

- What were the roadway and environmental conditions at the time of the crash?
- What were the critical events and contributing factors leading up to the crash and did these differ by crash type?
- What driver behaviors were present in the vehicle prior to the crash and did these differ by crash type?
- How did driver reaction times and eyes-off-road time differ relative to certain driver behaviors and crash types?
- Can drowsy driving be detected using this type of crash data?

Roadway and environmental conditions present in young-driver crashes

Roadway and environmental conditions varied considerably by crash type. Vehicle-to-vehicle crashes occurred most often on arterials and multi-lane, higher speed roads. These roadways commonly have numerous intersections, traffic lights and a higher rate of traffic flow. All present challenges for the teen that has learned to handle and maneuver a vehicle but may be struggling with scanning the roadway and recognizing hazards (McKnight & McKnight, 2003; Lee et al., 2008).

When time of day was investigated, a relatively high proportion of vehicle-to-vehicle crashes occurred between 6am and 9am. This increased from noon to 3pm, with a peak crash time occurring between 3pm and 6pm. This pattern is similar to that found by Williams (2003), which details a diurnal crash pattern distinct to teen drivers that peaks between 3pm and 7pm.

Single-vehicle crashes occurred most often on roads known as collectors, which connect local roads and streets with arterials, and included rural gravel roads in this study. These roadways typically have a lower traffic volume, which may cause a driver to become more complacent and less attentive. They also have less forgiving geometry, as well as narrow or

absent shoulders that leave little room for driver error. In addition, single-vehicle crashes occurred most often on roads that were fully or partially covered with snow/ice. Previous research has shown that single-vehicle crash fatalities involving young drivers are more likely to occur on wet or slippery roads (Marmor & Marmor, 2006). Newly licensed teens generally have a very limited experience driving under such conditions.

Single-vehicle crashes were three times as likely as vehicle-to-vehicle crashes to occur between the hours of 9 PM and 5:59 AM. This higher proportion of single-vehicle crashes at night is consistent with other research findings (Ivan et al., 2000; Williams and Preusser, 1997). Darkness, especially on rural collector roads, reduces visibility and site distance, making it more difficult to see the road edge as well as impending curves. Also, with darkness comes a drop in temperature and often deteriorated road conditions during inclement weather, making loss of control more likely. In addition, drivers may be more likely to be drowsy and less alert at this time. Conversely, vehicle-to-vehicle crashes may be less likely at this time due to lower traffic volumes. Williams & Preusser (1997) suggest that for teens, the higher frequency of single-vehicle crashes at night is also due to an increase in the number of passengers—particularly teen passengers—and a higher frequency of driver errors such as speeding.

Critical pre-crash events and potential contributing factors associated with young-driver crashes

Not surprisingly, the most common pre-crash events for single-vehicle crashes were the driver losing control of the vehicle or departing their lane. For vehicle-to-vehicle crashes the most common pre-crash events were: (1) a lead vehicle decelerating or stopped in the case of rear-end crashes, and (2) a vehicle crossing the centerline or turning at an intersection (regardless of whether it was the participant or another driver) in the case of angle crashes.

For this study, rear-end crashes in which the driver was hit from behind were removed from the database. Therefore, it is likely that the 94% of vehicle-to-vehicle crashes in which driver error was a contributing factor is inflated. However, in nearly all young-driver single-vehicle crashes examined, driver error was a contributing factor. It was observed in 99% of crashes, with many crashes having more than one driver error coded. This is higher than the results reported by Curry et al. (2011), who found that teen drivers made errors in nearly 80% of the teen crashes they examined. However, Curry et al. used data from the National Motor Vehicle Crash Causation Survey (NMVCCS), which relies on police reports and interviews of drivers. Driver errors may have been underreported, particularly for single-vehicle crashes, because they were not witnessed by anyone outside the vehicle, and drivers may not have been willing to admit their errors or in some cases may not have even been aware of them.

Studies that have examined the contributing factors or driver errors associated with young driver crashes have concluded that distraction/inattention, inadequate surveillance and speed are the most prevalent (McKnight & McKnight, 2003; Curry et al., 2011). Other detailed analyses of young driver crashes have found lack of vehicle control to be another common factor (Braitman et al., 2008; McGwin and Brown, 1999). This study confirmed these earlier results.

However, when driver errors were examined by crash type, we found that there was a difference in the types of errors that occurred most frequently. Single-vehicle crashes with loss of control generally involved a driver that was speeding or driving too fast for the conditions. Single-vehicle crashes that involved a road departure typically involved a driver who was inattentive or inadequately surveying the roadway. Rear-end and angle crashes were characterized by a higher frequency of inadequate surveillance and inattention. For angle crashes, there was also a high percentage of failure to yield ROW and failure to stop at signals and stop signs. These results are similar to what has been found in other studies that have looked at crash contributing factors using national crash databases (Campbell, 2003).

Type and frequency of driver behaviors present in young-driver crashes

Young drivers were seen engaging in some form of non-driving related behavior during the 6s leading up to 58% of crashes. This is consistent with the results of an in-depth study of crash causation conducted by Treat et al. (1979), which found some form of driver inattention in 56% of crashes. Since then, other studies have confirmed the prevalence of inattention/distraction and its role in crashes (Najm et al. 1994; Neale et al., 2005; Curry et al., 2011). In the official NHTSA databases, however, the proportion of crashes reported to involve distraction is much lower, 15-17% (NHTSA, 2010; 2013). Those data are derived from police reports, which are widely regarded as under-reporting the prevalence of distractions in crashes (Stutts et al., 2005). There is often a lack of willingness on the part of drivers to report engaging in potentially distracting behaviors at all, and to report specific behaviors in particular. This may be especially true for newly licensed teen drivers for whom the consequences are likely to be more severe. In addition, drivers may not even view the behaviors they were engaged in as relevant to the crash or even as potentially distracting, and may not report them for that reason.

Overall, attending to passengers was the most commonly observed driver behavior for all crash types, present in 14.9% of all crashes examined and varying little by crash type. When passengers were present, the driver was either looking at them or talking to them at some point in the 6s before the crash in approximately 40% of crashes. This result is consistent with other research in which teens reported their most common distraction as conversation with passengers (Royal, 2003; Tison et al., 2011). It is also consistent with the data from NMVCCS dataset, which found that passenger distraction represented the most significant distraction for teen drivers, and was present in 20% of young-driver crashes (Thor & Gabler, 2010).

Some research suggests that passengers in the vehicle increase a teen driver's crash risk (Doherty et al., 1998; Chen et al., 2000; Mayhew et al., 2003; Williams, 2003; Williams, Ferguson et al., 2007). However, it is not known whether the increased risk is due to social influence (Ouimet et al., 2013) and risk taking (Tefft et al, 2013), or whether teens simply lack the ability to divide their attention between the road and the conversation (Toxopeus et al., 2011; White & Caird, 2010; Gugerty et al, 2004). Conversely, other studies have found that passengers may increase situational awareness and help the driver to detect critical situations, leading to a decrease in crash risk and providing a protective effect (Rueda-Domingo et al., 2004; Vollrath et al., 2002; Engstrom et al., 2008).

This study could not determine whether passenger presence was associated with changes in crash risk, as only the prevalence of various conditions and factors in crashes was examined. However, our finding regarding the high frequency of passenger distractions is an important one. Several naturalistic driving studies (Klauer et al., 2006, Campbell, 2012) have had a limited ability to analyze frequency and types of passenger distractions due to limited camera views and a lack of audio which make it difficult to draw inferences regarding the nature of the interaction between the driver and passengers. In addition, lack of audio makes it extremely difficult to discern whether the driver was singing, engaged in conversation or talking on a hands-free phone. For these reasons, one could hypothesize that the prevalence of passenger distractions in other naturalistic research has been underreported.

Cell phone use was also one of the most common driver behaviors for all crash types, present in 11.9% of all crashes taken together, 10.8% of single-vehicle crashes, and 13.5% of vehicle-to-vehicle crashes. These results suggest a much higher prevalence of cell phone use than analyses of NHTSA's crash databases derived from police reports would suggest. NHTSA (2014) reports that in 2012, 16% of all police-reported crashes involved any driver distraction, and that 7% of crashes that involved some form of distraction (and 1.1% of all crashes) involved distraction due to cell phone use. Further examination of the crash data reported in NHTSA (2014) show that among drivers of the age group examined in the current study (ages 16-19), 14% were coded as having been distracted in some way, and 8% of those who were coded as distracted (1.1% of all crash-involved drivers ages 16-19) were coded as having been distracted due to cell phone use.

Interestingly, cell use was much more likely to occur when drivers were alone in the vehicle. A similar finding of higher electronic device use when a driver was alone in the vehicle was also found by Foss et al (2014). Perhaps when passengers are in the vehicle drivers did not feel the need to be in contact with others or perhaps drivers are more willing to engage in certain "risky" behaviors when they are alone than when they have passengers in the vehicle.

Attending to something non-driving related, either inside or outside the vehicle, was also one of the most commonly seen driver behaviors. These glances did not appear to be scanning-related, and could not be associated with any other secondary task. Although it is possible that the source of the glance was not visible to the analyst, another interesting possibility is that at least a portion of these glances might be indicative of cognitive distraction or mind wandering. Cognitive distractions and mind wandering are distinctly different types of behavior and it is likely that engagement in one or the other would have different consequences with regard to safety. However, to date, it has not been possible to definitively identify these behaviors or differentiate between them using naturalistic driving data. Additionally, one must be careful not to assume that just because a source of distraction is not visible to the analyst that a distraction is occurring inside the driver's mind.

Road departure and rear-end crashes were more likely to involve a driver engaging in a potentially distracting behavior than other crash types. With respect to vehicle-to-vehicle crash types, rear-end crashes were significantly more likely to have drivers engaged in a non-driving related behavior than angle crashes, a result that is consistent with other

studies (e.g., Neyens and Boyle, 2007). In single-vehicle crashes, drivers were significantly more likely to be engaged in non-driving-related behavior before a road-departure crash than a LOC crash. It is likely that the slippery road conditions that were associated with many LOC crashes may have made drivers less likely to engage in potentially distracting behaviors that would take their attention off the roadway.

Young-driver reaction time and eyes-off-roadway time in relation to behaviors and crash types

This study did not find a significant difference in reaction times among drivers who were engaged in a cell phone conversation (i.e., talking/listening) and those who were not. This was, however, based on only a small number of rear-end crashes in which a driver was only conversing on a cell phone but not looking at or physically manipulating the phone. Drivers who were looking at or operating a cell phone did have significantly slower reaction times, and this was a much more frequently observed crash scenario. The effects of talking on a cell phone while driving has been studied extensively, but results have been somewhat mixed. A simulator-based study by Strayer and Drews (2004) found that drivers who were engaged in a cell phone conversation had an 18% slower reaction time than those who were not, and were twice as likely to be involved in a rear-end crash (in a driving simulator). However, more recently, the results of several naturalistic driving studies have not found cell phone conversation alone to be associated with significant increases in crash risk when examined separately from dialing or manipulating the phone (Fitch et al., 2013; Klauer et al., 2014).

Reaction times of drivers with passengers in the vehicle were found to be even faster than those of drivers who were alone; they were even slightly faster when attending to a passenger. Drivers were also three times as likely to fail to react at all prior to a rear-end crash when they were alone than compared with when they had passengers and were attending to them. A simulator study by Drews et al. (2008) found that in many instances, passenger conversation is related to the surrounding traffic situation, aiding situational awareness. The complexity of the conversation also differs depending on the driving condition. In addition, passengers who become aware of a critical situation will most likely react in some way, helping to redirect the driver's attention. In the crashes examined in the current study, passengers alerted the driver of the impending collision before 32% of vehicle-to-vehicle crashes and 9% of single-vehicle crashes in which passengers were present, re-directing their attention and allowing the driver at least some time to react before the collision.

Drivers who were engaged in cell use had average eyes-off-road times that were more than twice as long as those of drivers who were attending to passengers (3.3s vs 1.5s). When cell use was broken down, the average eyes-off-road time for drivers who were operating or looking at their phone was 4.1s compared to 0.9s for drivers who were talking or listening. While the current study was unable to draw inferences regarding crash risk due to the absence of data on ordinary (non-crash) driving, other research has shown that tasks which result in a driver taking his or her eyes off of the forward roadway (e.g., dialing, reaching for a cell phone, and texting) significantly increase the risk of a crash or near-crash (Klauer et al., 2014), and that crash risk increases as eyes-off-road time increases (Simons-Morton et al., 2014). Thus, the findings of the current study regarding the high prevalence of cell

phone use in crashes—especially rear-end crashes and road-departure crashes—in conjunction with the long eyes-off-road times observed while manipulating cell phones suggests that countermeasures that prevent drivers from diverting their attention from the forward roadway could reduce young driver crash risk.

Using naturalistic driving data to detect drowsy driving

Driver fatigue was identified in less than 1% of the total crashes reviewed. However, we believe that these results likely underestimate the proportion of young driver crashes that involve drowsiness. The video data available for this study was recorded at only 4 Hz (four frames per second), making it difficult for the analysts to determine whether the driver's eyes had closed or if they were in the middle of a blink. Fatigue/drowsiness was only coded when a driver's eyes remained closed for more than 2 frames (>0.5s), and that was associated with yawning or head-bobbing behavior. Quality of night-time video was a further limitation as well, as it was sometimes difficult to see the driver's eyes clearly. Finally, only six seconds of video prior to each crash was examined—video from minutes before the crash, which may provide significant additional information regarding fatigue and drowsiness, were not available for the present study.

In contrast to the present study, Klauer et al. (2006) assessed driver drowsiness using continuous video for an extended period prior to crashes and near-crashes and estimated that drowsiness was present in about 20% of crashes and near crashes. Similarly, Tefft (2012) examined a sample of crashes in which a passenger vehicle was towed from the scene and estimated that 4.1% of all crash-involved drivers and 5.2% of crash involved young drivers (defined in that study as drivers aged 16-24) were drowsy.

Strengths and Limitations

Naturalistic driving studies allow researchers to examine many aspects of driving, and provide invaluable data that would not be available otherwise. The vast majority of studies of the environmental and behavioral factors involved in crashes have been based on data derived from police reports. While this information is helpful, it has many limitations. One important limitation is the lack of information regarding driver distraction, which is limited to what an officer was able to view or what a driver, passenger, or witness reported. This study allows us to report a wide range of driver and passenger behaviors. In addition, the data from this naturalistic study is able to provide a micro-level of detail about a crash, such as eye glances and reaction times—information unavailable in police-reported data.

A major advantage of this study is that it provides data from nearly 1,700 moderate-to-severe crashes. This is far larger than any other naturalistic driving study to date. For example, the 100-car Naturalistic Driving Study had 69 crashes, with 75% of those being non-police-reported low-*g* contact or curb strikes (Dingus et al., 2006). The SHRP2 naturalistic driving study is projected to have approximately 1,100 crashes; however, only a small number are expected to involve teenage driver crashes, and a large percentage of the crashes observed are likely to be relatively low in severity. Having such a large sample makes our findings more generalizable to the young-driver population. It also allowed us to

complete sub-analyses on errors and behaviors seen in crashes by whether a crash was a vehicle-to-vehicle or single-vehicle crash. In addition, we were able to investigate different types of crashes within these categories (rear-end vs angle, and LOC vs road departures) in relation to specific behavioral factors observed, to provide a more holistic view of these crash subtypes. Previous studies have not had sufficient power to examine crash types, and understanding the nuances of crash subtypes is vital to the prevention of crashes.

Another major advantage of this particular study, compared to naturalistic studies such as the 100-Car Naturalistic Driving Study or SHRP2, is that the current study had access to a view of the entire vehicle cabin as well as audio. This information provided us with a more comprehensive context of what was occurring during the six seconds before each crash. It was particularly important when examining crashes that involved passengers. Given the high frequency of young drivers attending to passengers highlighted both in our data and in previous research, it is important be able to investigate the nature of the interaction that occurs between a driver and passengers prior to crashes.

As with all naturalistic driving research there are concerns regarding the representativeness of the drivers involved in the study. Since the drivers in the crashes examined in the present study were simply driving and were not participating in a study at the time of their crashes, they may be slightly more representative of the population of young drivers than those who might voluntarily enroll in driving studies. However, these drivers were participating in a program intended to improve teen driver safety, and most were likely encouraged or required by their parents to participate. Drivers were aware that they were participating in the program and that their driving was being monitored, and one might argue that this would make them less likely to exhibit risky or aggressive driving behaviors, or to engage in potentially distracting behaviors. If this were the case, the frequency of driver behaviors reported may not be generalizable to all young drivers, and we hypothesize that the proportions reported may underestimate certain behaviors among the general driver population of young drivers. Nonetheless, even when participating in a teen driving program that involved video monitoring, potentially distracting driver behaviors were observed in more than half of all crashes.

In addition, the study participants were drawn primarily from the states of Colorado, Illinois, Iowa, Minnesota, Missouri, Wisconsin, and Nevada, not a random sample of all drivers nationwide, thus the traffic and weather conditions present in these states may have influenced the results to some degree. For example, many of these states receive a significant amount of wintery weather, which influences their driving conditions. As noted previously, a very high proportion of single-vehicle LOC occurred on roadways covered in snow and/or ice. While these results highlight the risks associated with snow and ice for teens living in these and similar states, this study likely overestimates the total proportion of teen driver crashes that involve single-vehicle LOC, and as noted, the behavioral factors present in single-vehicle LOC crashes differed in important ways from the behavioral factors present in other crash types. However, we also note that many of the single-vehicle LOC crashes were relatively minor and likely did not result in police reports being filed, thus, this study also provides insights into the full range of crash types that teen drivers experience, which could not be gained from examination of only police-reported crashes.

In addition, rear-end crashes in which the driver was hit from behind were not examined in the present study. Therefore, the estimated 94% of vehicle-to-vehicle crashes in which

driver error by the teen driver contributed to the crash almost certainly overestimates the proportion of *all* teen driver crashes in which an error by the teen driver plays a role in the crash. However, the results of this study allow us to describe what types of environments, road conditions, driver behaviors are present during rear-end crashes in which a teen driver crashes into the rear of another vehicle.

Although the large study sample made it possible to perform in-depth analyses of the relationships between specific factors and the types of crashes that occurred (specifically rear-end, angle, single-vehicle LOC, and single-vehicle road departure), the type of data analyzed here cannot be used to draw inferences regarding crash risk. Specifically, the video data examined in the present study was only available when a crash or other high g-force event triggered the recording of video; no video was available for ordinary uneventful non-crash driving, which precludes comparing the prevalence of various driver behaviors and other factors present in crashes versus in ordinary driving, which would be necessary in order to draw any inferences about the actual risk associated with any particular factor.

Finally, there are a few concerns regarding the IVERs used in this study and its ability to detect information that we know to be significant contributors to crashes. Global positioning system (GPS) data was not available, and therefore we could not assess vehicle speed for all crashes (speed data was available for less than 10% of crashes). In addition, drowsy driving and fatigue were difficult to determine due to the low frame rate (4 frames per second) and limited quality of nighttime video, and it is likely that 6s may not provide enough information to determine fatigue. While this study found a much higher prevalence of driver distraction than other studies have reported, the prevalence of drowsiness observable in this data was lower than in many other studies.

Conclusion

Use of in-vehicle event recorders in naturalistic driving allows researchers a unique view into the vehicle and provides invaluable information regarding the behavioral and environmental factors present before a crash. This type of data provides a much more detailed context relative to police reports and other crash databases, and allows analyses to be conducted at a more micro-level. This study examined the roadway and environmental conditions present in different types of crashes. It describes the critical events and contributing factors that lead up to crashes and how they vary by crash type. It also provides information regarding the relationship between specific driving behaviors and on reaction time and eyes-off-road time. Lastly, it is the first and largest naturalistic study of moderate-to-severe teen driver crashes to examine driver and passenger behaviors for a variety of crash types.

As expected, the environmental and roadway conditions varied considerably by crash type, with single-vehicle crashes being most affected by weather and surface conditions. Driver errors contributed to 94-99% of all young-driver crashes examined (note that crashes in which the young driver's vehicle was struck from behind by another vehicle were not examined). Recognition errors were more common in vehicle-to-vehicle crashes, while performance errors were more frequent in single-vehicle crashes. Although drivers were seen engaging in a wide range of behaviors leading up to a crash, the most common behavior among young drivers was attending to passengers. When passengers were present, the most common behavior observed was engaging in conversation with the driver.

Unexpectedly, reaction times were shorter when drivers were attending to passengers than when they were not. Another behavior frequently observed in young driver crashes was cell phone use, with operating/looking at the phone (e.g., texting or dialing) being observed most frequently. Drivers were significantly more likely to be using cell phones (for talking or texting) when alone in the vehicle than when passengers were present. While relatively rare in single-vehicle loss-of-control crashes, cell phone use was present in fully one third of road-departure crashes and nearly one-fifth of rear-end crashes in which the young driver struck the rear of another vehicle. Looking at or operating the cell phone was associated with long eyes-off-road time and slowed reaction time.

This study provides unique insights into the circumstances of and behavioral factors present in crashes of young drivers overall and in relation to crash type. Results indicate that there are different driver behaviors and contributing circumstances present in different types of crashes. The results of this study can be used to inform the development of education, training, and technology-based interventions aimed at improving the safety of young drivers.

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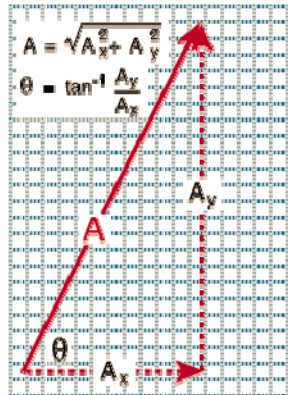
Appendix A. Vehicle-to-vehicle crash coding sheet

Variables	Codes
Event Number from DC	Alphanumerical
Month	Numerical
Day	Numerical
Year	Numerical
Day of the Week	Sunday Monday Tuesday Wednesday Thursday Friday Saturday
Time	Numerical
Time 2	AM PM
Manner of Collision *for pictures and clarification go to* http://www.mmucctraining.us/ ***sideswipe is coded when there is no significant involvement of the front or rear surface, the impact swipes along the surface of the vehicle parallel to the direction of travel***	Front to rear Front to front Angle Sideswipe, same direction Sideswipe, opposite direction Rear to front Rear to side Rear to rear Unknown
Forward g-force at impact	Numerical
Lateral g-force at impact	Numerical
Magnitude *(calculated based on the g-forces entered)*	Numerical For each crash, we were able to identify the lateral g-force at impact (A_x) and the forward g-force at impact (A_y). Using the Pythagorean relationship and triangle trigonometry (see Figure 1), we were able to calculate both the magnitude (A) and direction (Θ) of the force. Figure 1. Determining magnitude and direction of force at time of impact (Source: http://hyperphysics.phy-astr.gsu.edu/hbase/vect.html)
Angle *(calculated based on the g-forces entered)*	Numerical
Angle_360_0E *(calculated based on the angle)*	Numerical
Angle_360_0N *(calculated based on the angle)*	Numerical
Collision Vector Direction *(determined by the angle_360_0N)*	Front Front Left

	Left Front Left Left Rear Rear Left Rear Rear Right Right Rear Right Right Front Front Right
Impact Zone *(determined by the angle_360_0N)*	Front Front Left Left Front Left Left Rear Rear Left Rear Rear Right Right Rear Right Right Front Front Right
Weather *Code unknown when adverse weather is present but cannot be determined due to darkness (If possible, use street lights or headlights to determine)*	No adverse weather (i.e., clear/partly cloudy/cloudy) Fog Rain Sleet, hail, freezing rain Snow Unknown
Light *Dawn- the transition period going from "dark of night" to daylight. Typically the 30 minute period before sun rises.* *Dusk- the transition period going from daylight to "dark of night". Typically the 30 minute period after sun sets.* *If necessary, google time, time zone, and date to aid in coding.*	Daylight Degraded daylight (cloudy or **visible** weather- some/all vehicles w **headlights on**) Dawn/dusk (sun is not visible but there is daylight on horizon – some vehicles with **headlights on**) Dark, roadway lighted at location of critical event Dark, roadway not lighted at location of critical event
Road Type *(Assign crash to trafficway on which the first harmful event occurred. At intersection, assign the crash to the highest function class of trafficway.)* *http://ntl.bts.gov/lib/23000/23100/23121/09RoadFunction.pdf* *http://www.fhwa.dot.gov/environment/publications/flexibility/ch03.cfm*	Interstate • the largest and fastest of all these roads • parking is almost never permitted on expressways except for emergencies • the speed limits on expressways are usually greater than 55 mph • these are always multi-lane roads, with a minimum of 2 lanes in each direction • access is limited -- in other words, you can only get on or get off an expressway at certain points along the road. To get on an interstate, you need to drive on an arterial road to the entrance Arterial • generally be wider than local and collector roads • most are at least 4 lanes (2 in each direction) • the speed limit on arterials will be faster than on local and collector roads, ranging from 50 mph all the way up to 65 mph are common • parking is usually not permitted on arterials • commonly have lots of intersections and traffic lights • roads are usually, smooth, divided and wide Collector • are generally the same size as local roads • they may have houses or businesses adjacent to the road, and parking along the road may be permitted • connected to many local roads, and will 'feed' into even larger roads called arterials • speed limits are relatively higher, ranging from 30-45 • may or may not be divided • usually have a low flow rate. Local • have residents (houses, farms in rural areas, etc.) or businesses lining the road • speed limits are the slowest of all 4 types of roads, ranging from of 25 mph all the way down to 5 mph • these roads are only wide enough to support 2 lanes of traffic • parking is allowed along the side of these roads • provide access to the traffic emanating from the properties and discharge them onto collectors • usually have low traffic • frequent movements of children and adults Parking lot/ramp Entrance/exit ramp

	Driveway/alley
	Off road
	Unknown
Surface condition *(Determined at location of critical event)*	Dry Wet Ice Snow Mud, dirt Gravel Water (standing or moving) Other/Unknown
Vehicle speed at time of impact *Note: Only available for approximately 10% of the teen crashes*	This can be found in the Event Details only if GPS was provided for this crash. If it is not available, then leave blank to indicate "missing".

Critical/Precipitating Event	**This Vehicle Loss of Control Due to:**
(i.e., what action by this vehicle, another vehicle, person, animal, or non-fixed object was critical to this vehicle's crash?)	1. Blow out/flat tire
	2. Stalled engine
	3. Vehicle failure
	4. Poor road conditions
First determine the pre-crash category (main heading). Then decide on the pre-crash event under that heading that category. Only 1 critical event can be coded per crash.	5. Excessive speed
	6. Other
	This Vehicle Traveling:
	7. Stopped on roadway (includes parked on roadway)
	8. Decelerating on roadway
Note: Driveway is defined as a private way which provides access to the public from a trafficway to private property. Is considered to be not open to the public for transportation purposes as a trafficway.	9. With slower constant speed
	10. Over the line on the left side of travel
	11. Over the line on the right side of travel
	12. Over the left edge of roadway
Includes a private drive to a residence or private business.	13. Over the right edge of roadway
	14. Turning left at intersection
Excludes parking lots, which includes parking stalls, lots or ways	15. Turing right at intersection
	16. Passing through intersection
	Other Vehicle in Lane:
	17. Stopped on roadway
	18. Traveling in same direction with lower speed
	19. Traveling in same direction decelerating
	20. Traveling in same direction with higher speed
	21. Traveling in opposite direction
	22. In crossover
	23. Backing
	Another Vehicle Encroaching:
	24. From adjacent lane (same direction)- over lt lane line (i.e., other vehicle crosses its right lane line
	25. From adjacent lane (same direction)- over rt lane line (i.e., other vehicle crosses its left lane line
	26. From opposite direction over left lane line
	27. From opposite direction over right lane line
	28. From parking lane, median, shoulder, roadside
	29. From crossing street- turning in same direction
	30. From crossing street- across path
	31. From crossing street- turning into opposite direction
	32. From driveway- turning in same direction
	33. From driveway- straight across path
	34. From driveway- turning into opposite direction
	Pedestrian, Cyclist, Non-motorist:
	35. Pedestrian in roadway
	36. Pedestrian approaching roadway
	37. Cyclist/non-motorist in roadway
	38. Cyclist/non-motorist approaching roadway
	Object or Animal:
	39. Animal in roadway
	40. Animal approaching roadway
	41. Object in roadway
	42. Object approaching roadway

Contributing circumstances, Driver *Code all that are applicable* **Inadequate surveillance should be coded whenever traffic signals, road signs are missed OR BRT is poor >1 sec OR EOFR is >2 seconds* ***Rolling stop should be coded if there are not any frames without forward motion* ****Inattentive/distracted should be coded whenever there is a distraction coded as present*	Driving too fast for conditions Misjudged gap Inadequate surveillance ***See Note** Followed too close (**<2 seconds**) Ran traffic signal (**includes running yellow lights**) Ran stop sign (**includes rolling stops, see note****) Exceeded speed limit Made improper turn (turn from wrong lane or illegal u-turn) Travelling wrong way or on wrong side of road Crossed centerline Lost control (driver unable to maintain/regain control to avoid crash) Swerved to avoid an object/vehicle or animal in roadway Overcorrected/Over steering Operating in a reckless, aggressive or negligent manner Failed to yield ROW- from stop sign Failed to yield ROW- from yield sign Failed to yield ROW- making left turn Failed to yield ROW- making right on red Failed to yield ROW- from driveway Failed to yield ROW- from parked position Failed to yield ROW- to pedestrian Failed to yield ROW- at uncontrolled intersection Failed to yield ROW- entering roadway (from parking lots) Unsafe lane change Other illegal maneuver Inattentive/distracted *****See Note** Fatigued/tired (yawning) No improper action
Contributing circumstances, Environment *Code all that are applicable*	None apparent Weather Physical obstruction Pedestrian action Glare Animal in roadway Other
Contributing circumstances, Roadway *Code all that are applicable* ** Traffic back up is coded whenever there is an accumulation of traffic caused by vehicles slowing or stopping the traffic flow due to prior crashes, non-recurring events or regular congestion (see MMUCC)* *** Road surface condition should be coded when the BRT is good (<1sec) and max braking stays at a consistent level, indicating sliding or hydroplaning*	None apparent Traffic back up ***See Note** Road surface condition****See Note** Debris Ruts, holes, bumps Work zone Obstruction in roadway Traffic control device inoperative, missing Problem with road shoulder Pavement edge drop off
Reaction time to hazard- *ONLY code for rear end crashes in which leading vehicle brake lights are visible and both vehicles are travelling in the same lane. If the lv brake lights become visible but it is apparent that they had slowed or stopped much before that, do not code RT and make a note.*	Number of seconds between the time hazard appears and the driver reacts *(calculated for Front to Rear crashes- from onset of brake lights to active braking of > 0.15g)* *(In cases that are unclear, such as multiple instances of braking, do not code and make note)* *If the lead vehicle brake lights appear and the driver does not have a response before impact, RT should be coded as NRT (no reaction time)*

Driver Age *(approximate)*	1. 16-19
	2. 20-29
	3. 30-64
	4. 65+
Driver Gender	1. Male
	2. Female
	3. Unknown
Driver Condition	1. Normal
	2. Drowsy (**obviously** falling asleep)
	3. Driver visibly angry
	4. Driver visibly upset/crying
	5. Unknown
Driver Behavior *(code all that is seen from -6.0 seconds to impact)*	1. No observable behaviors
	2. Talking to self
	3. Reading map/directions/book
	4. Attending to passenger(s) (looking at/in conversation with)
	5. Attending to a moving object/animal inside vehicle
	6. Use of cell phone (talking, listening)
	7. Use of cell phone (operating, looking)
	8. Use of cell phone likely but not visible
	9. Adjusting in-vehicle controls
	10. Using electronic device (mp3, iPod, nav system)
	11. Reaching for object (picking object up/setting down, passing object to others)
	12. Eating or drinking
	13. Smoking related
	14. Personal grooming
	15. Attending to a person outside the vehicle
	16. Attending to another vehicle or passengers of another vehicle
	17. Looking for a street address
	18. Attending elsewhere, inside the vehicle
	19. Attending elsewhere, outside the vehicle
	20. Attending elsewhere, unknown
	21. Singing/dancing to the music
Vision possibly obscured by *(at time of critical event)*	1. No obstruction
	2. Rain, snow, fog, smoke, dust
	3. Glare (sun, headlights)
	4. Curve or hill
	5. Building, billboard
	6. Trees or other vegetation
	7. Moving vehicle
	8. Parked/stopped vehicle
	9. Inadequate clearing of windshield
	10. Obstruction in the interior of vehicle
	11. Other
Hands on wheel *(at time of critical event)* *Unless hands are visible or arm movement is very apparent, code as Unknown. Do not try to guess or spend a lot of time on this*	1. No hands
	2. One hand
	3. Both hands
	4. Unknown
Number of Passengers in the vehicle	Numerical

Passenger Characteristics (repeat for ALL passengers)	
Code passengers clockwise starting with the front seated passenger	
Age *(approximate)*	1. <1 (rear-facing car seat) 2. 1-4 (front- facing car seat) 3. 5-10 (booster seat) 4. 11-16 5. 16-19 6. 20-29 7. 30-64 8. 65+
Gender	1. Male 2. Female 3. Unknown
Passenger Behavior *(code all that is seen from -6.0 to impact)* (modified from Heck and Carlos, 2008)	**Passenger is:** 1. Not engaging in potentially distracting behavior 2. Talking to driver 3. Talking to other passenger(s) 4. Emotional (visibly angry or upset; includes infant/child crying, screaming) 5. Singing 6. Yelling 7. Making loud noises (i.e., whistling) 8. Moving around in the vehicle (turning around in seat, switching seats, wrestling, dancing, fighting with another px) 9. Adjusting vehicle controls 10. Giving directions 11. Pointing something out/showing driver something 12. Talking on the phone 13. Texting/using cell phone 14. Reaching for or dropped/spilled something 15. Purposely distracting driver (poking, tickling, grabbing, hitting) 16. Smoking related (lighting cigarette, handing cigarette to driver)
Social Influence ***When a passenger is pressuring the driver to behave in a more or less risky manner.*** *** Alerting the driver is coded when the passenger makes a movement or sound that redirects the driver's attention to the impending hazard***	1. Encouraging bad driving/or errors 2. Discouraging bad driving/or errors 3. Not an influence 4. Alerts driver *** see note**
Eye Glance Data	*NOTE: Transitions to and from the forward roadway should be appended to the glance* *Speed checks and rv mirror checks are NOT coded as glances off forward roadway* *If we can't see at least one eye, do NOT code. If we can see one eye, head position may be used to assist in coding* *If driver has glances in the direction of travel during a turn, rather than forward (toward oncoming traffic), code as inadequate surveillance and do not code glances as EOFR.* *If driver is approaching a stop sign/red light and begins scanning for their turn before coming to a stop, these glances are coded as EOFR* *If a driver is scanning before a lane change, these glances are coded as EOFR* *Glances are calculated from eyes off forward to their return to forward, multiple glance locations can occur within one glance*
Number of glances off roadway	Number of glances away from forward roadway during the 6 seconds prior to the impact
Total number of frames- eyes off road	Number of event frames eyes off roadway during the 6 seconds prior to the impact
Total time- eyes off road	Number of seconds the drivers eyes are off the forward roadway during the 6 seconds prior to the impact *(divide Total Number of frames by 4)*
Duration of longest glance	The duration of the longest glance that was initiated during the 6 seconds prior to the impact *(count frames and divide by 4)*

Notes	**Please make a note if:**
	• Airbag deployed • Driver wearing sunglasses (when coding of eye glances not possible) • Object in way of camera (when coding of eye glances not possible) • Anytime "other" is coded make sure to identify here • Describe any special circumstances • When crash is front to rear but reaction time cannot be coded, indicate why • Any coding questions should begin with "??" so that we can search for this and address later if necessary
Unbelted *Note: It is possible that two or more front (or rear) seated passengers could be unbelted; this would still be coded simply as a Front Px (Rear Px) was unbelted.*	Driver Driver and Front Px (passenger) Driver and Front Px and Rear Px Driver and Rear Px Front Px Front Px and Rear Px Rear Px
Airbag deployed	Yes If blank, there was not an airbag deployment visible during the video
Possibly drowsy/asleep *indicated by yawning, shaking of head, eye closures that seem long, mention in notes that drowsiness might be a factor*	Yes If blank, there was no indication that the driver might be drowsy/asleep

Traffic Control Present
Only coded for those events with the critical event coded under the category of "This vehicle traveling" or "Another vehicle encroaching"
	This vehicle traveling:
	    No controls present
	    Stop sign
	    Stop sign at t-intersection
	    2-way stop sign
	    4-way stop sign
	    Traffic light- flashing signal
	    Traffic light- left on solid green (unprotected left turn)
	    Traffic light- left on yellow/red
	    Traffic light- right on red
	    Traffic light- straight on red
	    Traffic light- straight on yellow/red
	    Unknown, exiting parking lot
	
	Another vehicle encroaching:
	    No controls present
	    Stop sign
	    Traffic light
	    2-way stop sign
	    4-way stop sign
	    Cross traffic entering from parking lot
	    Cross traffic had flashing red
	    Cross traffic had red light
	    Cross traffic had stop sign
	    Cross traffic had yield in roundabout
	    Cross traffic turned right on red
	    Cross traffic turned left on solid green (unprotected left turn)
	    Cross traffic turned left on yellow

Appendix B. Single-vehicle crash coding sheet

Variables	Codes
Event Number from DC	Alphanumerical
Month	Numerical
Day	Numerical
Year	Numerical
Day of the Week	Sunday Monday Tuesday Wednesday Thursday Friday Saturday
Time	Numerical
Time 2	AM PM
Weather *If it is dark, weather should be coded as unknown unless visible in street lights or headlights (i.e., fog, rain, snow, sleet, hail, freezing rain)*	No adverse weather (i.e., clear/partly cloudy/cloudy) Fog Rain Sleet, hail, freezing rain Snow Unknown
Light *Dawn- the transition period going from "dark of night" to daylight. Typically the 30 minute period before sun rises.* *Dusk- the transition period going from daylight to "dark of night". Typically the 30 minute period after sun sets.* *If necessary, google time, time zone, and date to aid in coding.*	Daylight Degraded daylight (cloudy or **visible** weather- some/all vehicles w **headlights on**) Dawn/dusk (sun is not visible but there is daylight on horizon – some vehicles with **headlights on**) Dark, roadway lighted at location of critical event Dark, roadway not lighted at location of critical event
Road Type *(Assign crash to trafficway on which the first harmful event occurred. At intersection, assign the crash to the highest function class of trafficway.)* *Interstates- high speeds over long distances- 55-75mp* *Arterials- freeways and multi-lane highways, connect urbanized areas, cities, and industrial centers- 50-70mph* *Collectors-major and minor roads that connect local roads and streets with arterials, balance mobility with land access- 35-55mph. Rural gravel roads coded as such.* *Local- limited mobility, primary access to residential areas, businesses, farms- speeds up to 25mph* *http://ntl.bts.gov/lib/23000/23100/23121/09RoadFunction.pdf* *http://www.fhwa.dot.gov/environment/publications/flexibility/ch03.cfm*	Interstate Arterial Collector Local Parking lot/ramp Entrance/exit ramp Driveway/alley Off road Unknown
Edge type **When there is snow/ice on part or all of the edge of roadway code as snow/ice. Do not assume the presence of curb or shoulder if edge is covered with snow/ice.*	Curb No shoulder, no curb Hard shoulder (i.e., paved/asphalt/chip and seal) Soft shoulder (i.e., loose gravel/dirt/grass) Snow or ice*

Surface condition *(Determined at location of critical event)*	Dry Wet Ice Snow Mud, dirt Gravel Water (standing or moving) Other/Unknown
Vehicle speed at time of impact *Note: Only available for approximately 10% of the teen crashes*	This can be found in the Event Details only if GPS was provided for this crash. If it is not available, then leave blank to indicate "missing".
Max FWD force	Max force during the crash
Max LAT force	Max force during the crash
Manner of Collision *for pictures and clarification go to* http://www.mmucctraining.us/	Not a collision with a vehicle—should be the case for all single-vehicle crashes
Pre-crash Movement	Going straight Merging Changing lanes Turning right at intersection Turning left at intersection Negotiating a curve to the right Negotiating a curve to the left Avoidance maneuver
Sequence of Event1 through 5 **(can include up to 5 events in a sequence)** ***Cross centerline- only code when both front or both rear tires have crossed the centerline. Use imaginary centerline in cases where one is not present.**	Ran off road- right Ran off road- left Run off road- straight (end departure at t-intersection) Cross median Cross centerline* Re-enter road Collision with curb Collision with object not fixed Collision with fixed object Rollover/overturn
Object not fixed	Pedestrian Cyclist Railway vehicle Live animal Ridden animal or animal drawn conveyance Non-motorist on personal conveyance Parked motor vehicle Working vehicle (i.e., construction, maintenance vehicle) Other object not fixed
Fixed object	Boulder Building Ground Impact attenuator/crash cushion Bridge structure Guardrail Concrete traffic barrier Cable barrier Traffic sign support Traffic signal support Utility pole/light support Other post/pole/support Culvert Curb Ditch

	Embankment Fence Wall Fire hydrant Shrubbery Tree Snowbank Mailbox Utility box Other/unknown
Conflict Classification	Leave road and crash off road Leave road, crash, return to road Leave road, crash, return to road and continue driving Leave road, no crash, ability to return to road unknown Leave road, no crash, cannot return to road Leave road, no crash, return to road and continue driving
Critical/Precipitating Event *(i.e., what action by this vehicle, another vehicle, person, animal, or non-fixed object was critical to this vehicle's crash?)* *First determine the pre-crash category (main heading). Then decide on the pre-crash event under that heading that category. Only 1 critical event can be coded per crash.* *Note: Driveway is defined as a private way which provides access to the public from a trafficway to private property. Is considered to be not open to the public for transportation purposes as a trafficway.* *Includes a private drive to a residence or private business.* *Excludes parking lots, which includes parking stalls, lots or ways*	**This Vehicle Loss of Control Due to:** 1. Blow out/flat tire 2. Stalled engine 3. Vehicle failure 4. Poor road conditions 5. Excessive speed 6. Other **This Vehicle Traveling:** 7. Stopped on roadway (includes parked on roadway) 8. Decelerating on roadway 9. With slower constant speed 10. Over the line on the left side of travel 11. Over the line on the right side of travel 12. Over the left edge of roadway 13. Over the right edge of roadway 14. Turning left at intersection 15. Turing right at intersection 16. Passing through intersection **Other Vehicle in Lane:** 17. Stopped on roadway 18. Traveling in same direction with lower speed 19. Traveling in same direction decelerating 20. Traveling in same direction with higher speed 21. Traveling in opposite direction 22. In crossover 23. Backing **Another Vehicle Encroaching:** 24. From adjacent lane (same direction)- over lt lane line (i.e., other vehicle crosses its right lane line 25. From adjacent lane (same direction)- over rt lane line (i.e., other vehicle crosses its left lane line 26. From opposite direction over left lane line 27. From opposite direction over right lane line 28. From parking lane, median, shoulder, roadside 29. From crossing street- turning in same direction 30. From crossing street- across path 31. From crossing street- turning into opposite direction 32. From driveway- turning in same direction 33. From driveway- straight across path 34. From driveway- turning into opposite direction **Pedestrian, Cyclist, Non-motorist:** 35. Pedestrian in roadway 36. Pedestrian approaching roadway

	37. Cyclist/non-motorist in roadway 38. Cyclist/non-motorist approaching roadway **Object or Animal:** 39. Animal in roadway 40. Animal approaching roadway 41. Object in roadway 42. Object approaching roadway
Contributing circumstances, Driver *Code all that are applicable* **Inadequate surveillance should be coded whenever traffic signals, road signs are missed OR BRT is poor >1 sec OR EOFR is >2 seconds* ***Rolling stop should be coded if there are not any frames without forward motion* ****Inattentive/distracted should be coded whenever there is a distraction coded as present*	Driving too fast for conditions Misjudged gap Inadequate surveillance ***See Note** Followed too close (**<2 seconds**) Ran traffic signal (**includes running yellow lights**) Ran stop sign (**includes rolling stops, see note****) Exceeded speed limit Made improper turn (turn from wrong lane or illegal u-turn) Travelling wrong way or on wrong side of road Crossed centerline Lost control (driver unable to maintain/regain control to avoid crash) Swerved to avoid an object/vehicle or animal in roadway Overcorrected/Over steering Operating in a reckless, aggressive or negligent manner Failed to yield ROW- from stop sign Failed to yield ROW- from yield sign Failed to yield ROW- making left turn Failed to yield ROW- making right on red Failed to yield ROW- from driveway Failed to yield ROW- from parked position Failed to yield ROW- to pedestrian Failed to yield ROW- at uncontrolled intersection Failed to yield ROW- entering roadway (from parking lots) Unsafe lane change Other illegal maneuver Inattentive/distracted *****See Note** Fatigued/tired (yawning) No improper action
Contributing circumstances, Environment *Code all that are applicable*	None apparent Weather Physical obstruction Pedestrian action Glare Animal in roadway Other
Contributing circumstances, Roadway *Code all that are applicable* ** Traffic back up is coded whenever there is an accumulation of traffic caused by vehicles slowing or stopping the traffic flow due to prior crashes, non-recurring events or regular congestion (see MMUCC)* *** Road surface condition should be coded when the BRT is good (<1sec) and max braking stays at a consistent level, indicating sliding or hydroplaning*	None apparent Traffic back up ***See Note** Road surface condition****See Note** Debris Ruts, holes, bumps Work zone Obstruction in roadway Traffic control device inoperative, missing Problem with road shoulder Pavement edge drop off
Driver Age *(approximate)*	1. 16-19 2. 20-29 3. 30-64 4. 65+

Driver Gender	1. Male
	2. Female
	3. Unknown
Driver Condition	1. Normal
	2. Drowsy (**obviously** falling asleep)
	3. Driver visibly angry
	4. Driver visibly upset/crying
	5. Unknown
Driver Behavior *(code all that is seen from -6.0 seconds to impact)*	1. No observable behaviors
	2. Talking to self
	3. Reading map/directions/book
	4. Attending to passenger(s) (looking at/in conversation with)
	5. Attending to a moving object/animal inside vehicle
	6. Use of cell phone (talking, listening)
	7. Use of cell phone (operating, looking)
	8. Use of cell phone likely but not visible
	9. Adjusting in-vehicle controls
	10. Using electronic device (mp3, iPod, nav system)
	11. Reaching for object (picking object up/setting down, passing object to others)
	12. Eating or drinking
	13. Smoking related
	14. Personal grooming
	15. Attending to a person outside the vehicle
	16. Attending to another vehicle or passengers of another vehicle
	17. Looking for a street address
	18. Attending elsewhere, inside the vehicle
	19. Attending elsewhere, outside the vehicle
	20. Attending elsewhere, unknown
	21. Singing/dancing to the music
Vision possibly obscured by *(at time of critical event)*	1. No obstruction
	2. Rain, snow, fog, smoke, dust
	3. Glare (sun, headlights)
	4. Curve or hill
	5. Building, billboard
	6. Trees or other vegetation
	7. Moving vehicle
	8. Parked/stopped vehicle
	9. Inadequate clearing of windshield
	10. Obstruction in the interior of vehicle
	11. Other
Hands on wheel *(at time of critical event)* *Unless hands are visible or arm movement is very apparent, code as Unknown. Do not try to guess or spend a lot of time on this*	1. No hands
	2. One hand
	3. Both hands
	4. Unknown
Number of Passengers in the vehicle	Numerical
Passenger Characteristics (repeat for ALL passengers) **Code passengers clockwise starting with the front seated passenger**	
Age *(approximate)*	1. <1 (rear-facing car seat)
	2. 1-4 (front- facing car seat)
	3. 5-10 (booster seat)
	4. 11-16
	5. 16-19
	6. 20-29
	7. 30-64
	8. 65+
Gender	1. Male
	2. Female
	3. Unknown

Passenger Behavior *(code all that is seen from -6.0 to impact)* (modified from Heck and Carlos, 2008)	**Passenger is:** 1. Not engaging in potentially distracting behavior 2. Talking to driver 3. Talking to other passenger(s) 4. Emotional (visibly angry or upset; includes infant/child crying, screaming) 5. Singing 6. Yelling 7. Making loud noises (i.e., whistling) 8. Moving around in the vehicle (turning around in seat, switching seats, wrestling, dancing, fighting with another px) 9. Adjusting vehicle controls 10. Giving directions 11. Pointing something out/showing driver something 12. Talking on the phone 13. Texting/using cell phone 14. Reaching for or dropped/spilled something 15. Purposely distracting driver (poking, tickling, grabbing, hitting) 16. Smoking related (lighting cigarette, handing cigarette to driver)
Social Influence *When a passenger is pressuring the driver to behave in a more or less risky manner.* ** Alerting the driver is coded when the passenger makes a movement or sound that redirects the driver's attention to the impending hazard*	1. Encouraging bad driving/or errors 2. Discouraging bad driving/or errors 3. Not an influence 4. Alerts driver *** see note**
Eye Glance Data	*NOTE: Transitions to and from the forward roadway should be appended to the glance* *Speed checks and rv mirror checks are NOT coded as glances off forward roadway* *If we can't see at least one eye, do NOT code. If we can see one eye, head position may be used to assist in coding* *If driver has glances in the direction of travel during a turn, rather than forward (toward oncoming traffic), code as inadequate surveillance and do not code glances as EOFR.* *If driver is approaching a stop sign/red light and begins scanning for their turn before coming to a stop, these glances are coded as EOFR* *If a driver is scanning before a lane change, these glances are coded as EOFR* *Glances are calculated from eyes off forward to their return to forward, multiple glance locations can occur within one glance*
Number of glances off roadway	Number of glances away from forward roadway during the 6 seconds prior to the impact
Total number of frames- eyes off road	Number of event frames eyes off roadway during the 6 seconds prior to the impact
Total time- eyes off road	Number of seconds the drivers eyes are off the forward roadway during the 6 seconds prior to the impact *(divide Total Number of frames by 4)*
Duration of longest glance	The duration of the longest glance that was initiated during the 6 seconds prior to the impact *(count frames and divide by 4)*
Notes	**Please make a note if:** • Airbag deployed • Driver wearing sunglasses (when coding of eye glances not possible) • Object in way of camera (when coding of eye glances not possible) • Anytime "other" is coded make sure to identify here • Describe any special circumstances • When crash is front to rear but reaction time cannot be coded, indicate why • Any coding questions should begin with "??" so that we can search for this and address later if necessary

Unbelted *Note: It is possible that two or more front (or rear) seated passengers could be unbelted; this would still be coded simply as a Front Px (Rear Px) was unbelted.*	Driver Driver and Front Px (passenger) Driver and Front Px and Rear Px Driver and Rear Px Front Px Front Px and Rear Px Rear Px
Airbag deployed	Yes If blank, there was not an airbag deployment visible during the video
Possibly drowsy/asleep *indicated by yawning, shaking of head, eye closures that seem long, mention in notes that drowsiness might be a factor*	Yes If blank, there was no indication that the driver might be drowsy/asleep