Assessing the Residual Teen Crash Risk Factors after Graduated Drivers License Implementation

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ABSTRACT – Graduated driving licensing laws are now in place in all 50 U.S. states and the District of Columbia. However, despite stricter supervised driving requirements, restrictions on the number of passengers, and earlier nighttime driving curfews, teen drivers continue to be at a higher crash risk than the adult driving population. The National Motor Vehicle Crash Causation Survey (NMVCCS) dataset was examined to compare and contrast the primary crash factors for teen drivers (16-18 years. old) and adult drivers (35-55 years. old) in the GDL era. It is was found that teen drivers were 2.40 (CI:1.19-4.85) times more likely to be in a control loss crash and 1.88 (CI:1.12-3.15) times more likely to be in a road departure crash relative adult drivers. Furthermore, teen drivers who were in a crash were 1.73 (CI:1.25-2.38) times more likely to be distracted, 1.83 (CI: 1.38-2.43) times more likely to be driving inappropriately, and 1.47 (CI:1.30-1.67) times more likely to be inadequately aware of their driving environment than adults. Passengers and aggressive driving also contributed significantly to the heightened crash risk for teen drivers, after GDL implementation. This study emphasizes that while the number of teen crashes has decreased with GDL, the relative crash risk for certain experience related causative factors and pre-crash scenarios remain high for teen drivers after GDL implementation nationwide.

INTRODUCTION

An analysis of the Fatal Analysis Reporting System (FARS) shows that, from 2005-2008 there was an average of 4,800 fatalities each year in motor vehicle crashes involving a teen driver. This accounted for 13.3% of all fatalities in motor vehicle crashes, yet teen drivers only accounted for 4.8% of all licensed drivers [FHWA, 2008]. Furthermore, motor vehicles continue to be the leading cause of death for all persons aged 13-19 years old, despite an overall decline in teen fatalities over the last two decades [IIHS, 2009]. Teen fatalities in motor vehicle crashes (MVCs) are believed to occur for a number of reasons ranging from driver inexperience, inability to deal with distractions, and a propensity for excessive risk taking among some teens.

Graduated Driver's Licensing

Graduated driving licensing laws have been implemented in all 50 U.S. states and the District of Columbia [IIHS, 2010a]. GDL licensing regulations allow for the gradual accumulation of driving experience for teen drivers through practice in lower risk driving scenarios. These programs often require a period of supervised driving, restrictions on the number of passengers, restrictions on the hours of operation, or any combination of these and other regulations. In 1996, Florida became the first state to implement a modern GDL system in the U.S. [Doherty, 1997; Ulmer, 2000]. All other states have updated their licensing laws since this time to include at least some features of a GDL program. However, significant differences exist between each state's licensing laws.

The learner's permit stage is a primary component of many GDL programs and requires increased supervised driving prior to full licensure. Crashes under supervised conditions are relatively infrequent. The learner's permit stage has provided a low crash risk training process for a new driver [Mayhew, 2003]. However, when novice drivers graduate from this licensing stage and begin unsupervised driving, their crash risk spikes [Gregersen, Nyberg and Berg, 2003; Mayhew, Simpson and Pak, 2003; McCartt, Shabanova and Leaf, 2003]. Any beginning driver, regardless of age or maturity, possesses a higher crash risk than more experienced drivers, particularly within the first few months of unsupervised driving. Both age (i.e. maturity) and experience have been identified as the largest contributors to increased teen crash risk [Williams, 1999; Mayhew, 2003; Mayhew et al., 2003; Simpson, 2003; Waller, 2003; Williams, 2003]. Furthermore, excessive risk taking amongst some teens has often been cited as a factor in the increased crash rate [Mayhew et al., 2003].

Efforts to minimize the factors that may increase the likelihood of an unsupervised teen driver crash are an essential component of GDL programs. For instance, the number of passengers in a teen driver vehicle has been shown to be directly correlated to increased crash risk [Chen, Baker, Braver, 2000]. As a result, restrictions on the allowed number of passengers for those licensed in the provisional stages has become an integral part of GDL regulation [Williams, 2003]. Furthermore, a restriction on nighttime driving has also been shown to effectively reduce teen crashes [Foss, Feaganes and Rodgman, 2001; Shope and Molnar, 2004]. The inclusion of these regulations is supported by the fundamental pro-GDL argument: crash risk can be reduced by limiting the exposure of the novice driver to more complicated driving scenarios and by limiting driver distractions.

The factors associated with teen driver crash risk are complex, and GDL regulations vary widely from state to state. The technical literature on GDL reflects this complexity and non-standardization. Nonetheless, the majority of studies have shown a net reduction in teen crash rates of 20-30% after the implementation of GDL [Shope and Molnar, 2003; Simpson, 2003; Williams, 2006].

Residual Teen Crash Risk

Much of the research devoted to the study of GDL has focused on the effectiveness of a specific state's regulation for reducing teen crash or fatality risk. Furthermore, studies that explore teen driver risk factors, e.g. night-time driving or driving with passengers, have also been focused on the results within a single state or were conducted prior to GDL implementation. Despite the fact that all states have some form of GDL, teen drivers continue to have higher crash and fatality risks, nationally compared to more experienced drivers. In this study, we hope to identify the factors that continue to contribute to these elevated teen driver crash risks. This may support the argument that teen crashes and fatalities can be further reduced by appropriately enhancing or adding to existing GDL regulations.

Evaluating Pre-Crash Behaviors

Identifying pre-crash events and behaviors of teen drivers is necessary for an assessment of the residual factors that continue to produce an elevated teen crash risk. Previously published methods for collecting the pre-crash information are varied in their approach and data sources. One method utilizes surveys of teen drivers to obtain crash causation information [Laapotti, Keskinen, Hatakka, 2006]. However, this information relied on self-reporting and the surveys were often completed long after the event occurred. Other approaches have developed taxonomies to characterize pre-crash events and behaviors in existing datasets to illustrate the circumstances that lead to crash events for all drivers [Najm, Smith and Yanagisawa, 2007; Eigen and Najm, 2009]. However, the datasets available at the time of these studies had only limited data on pre-crash behaviors. Hendricks, Fell, and Freedman (1999) developed a crash causation dataset based on the crash investigation and sampling techniques of National Automotive Sampling System Crashworthiness Data System (NASS/CDS), coupled with additional data collection for the causal factors in the crash. While this dataset was not nationally representative, its focus on pre-crash behaviors was able to illustrate the distribution of pre-crash factors in a large number of cases.

More recently, the National Highway Traffic Safety Administration (NHTSA) has released the National Motor Vehicle Crash Causation Survey (NMVCCS) dataset which promises new insights into the circumstances that lead to crashes [Bellis and Page, 2008]. NMVCCS is a unique crash investigation dataset, which focuses on the circumstances and factors that contribute to a crash. This dataset relies heavily on driver interviews conducted at the scene and on-site evidence collection. This provides a unique opportunity to address some of the issues that have served as limitations in other studies such as timeliness of data collection, limited focus on pre-crash factors, or lacking national representation. This dataset can provide insight into the pre-crash events and behaviors that continue to produce the elevated teen crash risk in the United States, despite GDL implementation.

Objective. Identify the factors that continue to produce an elevated teen driver crash risk after GDL implementation in the United States.

METHODS

This study analyzed the propensity of teen drivers to be involved in crashes that result from certain pre-crash events and behaviors by comparing their crash distributions to adult drivers. For this study, teens were defined as individuals of age 16-18 years old. Adults were defined as individuals of 35-55 years old. The analysis has been restricted to 16-18 year old drivers in crashes, as these are the ages that are most directly affected by GDL. This age range includes those who are driving with a permit, those who are provisionally licensed, as well as those who have recently graduated from the GDL program.

The NMVCCS dataset was analyzed to determine the primary pre-crash circumstances and behaviors that are associated with an elevated teen driver crash risk. NMVCCS is unlike other NHTSA crash datasets because the investigations primarily focused on obtaining evidence and conducting interviews that would explain the causes of the crash. NMVCCS is a nationally representative dataset that includes crashes which occurred from July 3, 2005 to December 31, 2007 between the hours of 6:00am and 11:59pm. Prior to the beginning of the NMVCCS data collection period in 2005, all states and the District of Columbia had implemented at least one component of the modern GDL program with the exception of Wyoming and Montana, which instituted their first GDL regulations in September, 2005 and July, 2006, respectively [IIHS, 2010a].

During data collection, NMVCCS relied on special arrangements between crash investigators, EMS, and police agencies as well as constant monitoring of crash occurrences with the aid of police scanners to allow for immediate crash-site investigations and on-site driver interviews. To further ensure the accuracy of the data and inhibit the loss of critical information, it was required that a responding officer was on-scene at the time of the crash investigation and a particular focus was placed on driver interviews. This provided an opportunity to collect evidence and conduct interviews with the involved parties immediately after the crash regarding the pre-crash events and behaviors.

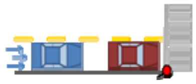
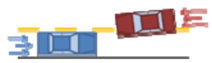
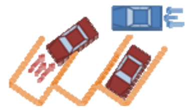
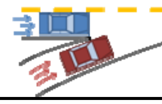
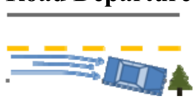
The pre-crash behaviors we analyzed included inappropriate driving (e.g. speeding, weaving), inadequate driving performance (e.g. failure to observe surroundings, following too closely), distractions (e.g. conversations, adjusting radio controls), as well as environmental factors. We also compared crash risk by categorizing pre-crash event scenarios to check the hypothesis that even after GDL implementation, teens might have a heightened crash risk resulting from certain pre-crash events.

A pre-crash classification methodology, unique to this dataset, was developed to identify these crash scenarios. The fundamental basis for this classification method was based on the pre-crash event classification methodology employed by Najm (2007) and Eigen (2009). Their methodology characterized each crash into 1 of 37 pre-crash event scenarios based on the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) and the National Automotive Sampling System / General Estimates System (NASS/GES). Using a similar approach, we grouped each crash in the NMVCCS database into 1 of the 9 pre-crash event categories shown in Table 1. The category of each crash was based on the number of involved vehicles, the pre-crash events, pre-crash vehicle movement pattern, and accident type. Pre-crash events included lane departures, control loss, or lane encroachment (NMVCCS variable: PREEVENT). Pre-crash vehicle movement patterns included driving straight, decelerating, or turning (NMVCCS variable: PREMOVE). Accident types included driving off the road, rear-end, or forward impact (NMVCCS variable: ACCTYPE).

The distributions of pre-crash behaviors, given as a percentage of all crashes for each age range, were computed to determine the factors that were most frequently present. Risk ratios were computed to determine the pre-crash behaviors and pre-crash event categories that were most frequently associated with teen driver crashes. To identify these factors, the crashes involving teen drivers (16-18 yrs. old) were compared to those involving adult drivers (35-55 yrs. old). This method provided a comparison population (adult drivers) consisting of an age range where the drivers were not subject to the GDL regulations, but were assumed to have been exposed to the same driving environment. Other methods for comparing teen driver crash rates such as the induced exposure method or comparing the teen crash rates in neighboring states have been used in other studies [Ulmer, 1999; Ulmer, 2000; Ulmer, 2001; Rice, Peek-Asa and Kraus, 2004; Fohr, Layde and Guse, 2005]. Equation 1 shows the method in which risk ratios were calculated in this study. Teen and adult crashes "x" represent the number of crashes that occurred with the presence of a given crash factor. Risk ratio values greater than one indicated that the crash factor of interest was represented more frequently in teen driver crashes than adult driver crashes. In other words, a risk ratio of 2 for a specific pre-crash event would indicate that the pre-crash factor of interest was twice as likely to be represented in teen driver crashes as compared to adult driver crashes. Risk ratios were also computed to determine if certain teen driver pre-crash behaviors were seen more frequently in the pre-crash event scenarios for teen drivers relative to those who were not engaged in these behaviors (e.g. the risk of a road departure crash for a distracted teen driver compared to the risk of a road departure crash for a non-distracted teen driver).

$$RR = \frac{\left(\dfrac{Teen\ Crashes\ (x)}{All\ Teen\ Crashes}\right)}{\left(\dfrac{Adult\ Crashes\ (x)}{All\ Adult\ Crashes}\right)} \qquad (1)$$

Table 1. Pre-crash event classification categories

Action/Inaction Resulting in a Rear-End Crash	Interaction w/ a Vehicle from in Opposite Direction	Object / Animal / Person in Road
		
Intersection Turning / Cross Paths	**Event Resulting from Other Vehicle's Actions**	**Same Direction / Merging**
		
Road Departure	**Control Loss**	**Other / Unknown**
		

For all calculations, the Taylor series linearization was employed to approximate the variance within the clusters and strata of the dataset sample design. Based on these variance estimations, 95%-tile confidence intervals were computed. Statistical computations were performed with the SAS v9.2 software package using the SURVEYFREQ and SURVEYMEANS procedures (SAS Institute inc., Cary, NC). Finally, it should be noted that the percentages within the crash causation categories in the appendix often sum to more than 100%. Frequently, there is more than one crash causation factor in a crash (e.g. a driver may be talking on the phone and adjusting the radio controls). Therefore, this crash would be counted in both categories.

RESULTS

For our study, the analyses were based on the characterization of 801 teen (16-18 yr. olds) crashes and 3,159 adult (35-55 yr. olds) crashes extracted from NMVCSS. After application of the national weighting factors, this represents 320,358 teen crashes and 1,179,490 adult crashes.

This section presents a discussion of the risk ratios associated with pre-crash event categories and pre-crash behaviors, and the relationship between the pre-crash behavioral factors and the pre-crash events. The appendix presents an expanded listing of the distributions of pre-crash events, pre-crash behaviors, environmental factors, and dataset composition.

Table 2 shows that, when compared to adult drivers, teen drivers who were in a crash were roughly two and a half times as likely to be in a control loss crashes and almost twice as likely to be in a road departure crash.

Table 2. Risk ratios (RR) showing the relative likelihood of a teen driver crash following a pre-crash event, relative to the adult driver crash ratio.

Pre-Crash Classification	Teen	Adult	RR (95% CI)	
Control Loss	**8.1%**	**3.4%**	**2.40** (1.19-4.85)	*
Road Departure	**23.2%**	**12.4%**	**1.88** (1.12-3.15)	*
Person / Animal / Object in Road	**1.3%**	**0.8%**	**1.64** (0.18-15.0)	
Rear-End	**13.6%**	**9.4%**	**1.44** (0.91-2.27)	
Opposite Direction	**3.1%**	**6.8%**	**0.39** (0.20-0.74)	*
Event Resulting from Other Vehicle's Actions	**2.8%**	**12.3%**	**0.23** (0.13-0.42)	*
Same Direction / Merging	**3.1%**	**6.0%**	**0.52** (0.37-0.74)	*
Intersection Turning / Cross Paths	**40.4%**	**43.8%**	**0.99** (0.79-1.24)	
Other	**3.9%**	**4.1%**	**0.39** (0.13-1.15)	

* - Statistically significant result (α = 0.05).

Table 3. Risk ratios (RR) showing the relative likelihood of a teen driver crash following a pre-crash behavior, relative to the adult driver crash ratio.

Pre-Crash Behaviors	Teen	Adult	RR (95% CI)	
Distracted Driver Crashes	34.4%	19.9%	**1.73** (1.25-2.38)	*
Conversing	18.0%	9.4%	**1.91** (1.41-2.59)	*
Other Distraction	13.1%	5.3%	**2.48** (1.20-5.12)	*
Exterior Factor	11.1%	7.3%	**1.53** (0.94-2.49)	
Inappropriate Driving	24.1%	13.1%	**1.83** (1.38-2.43)	*
Illegal Maneuver	8.1%	7.9%	**0.93** (0.40-2.12)	
Aggressive Act	10.6%	3.4%	**3.42** (1.17-7.09)	*
In a Hurry	7.6%	3.9%	**1.94** (1.03-3.65)	*
Inadequate Awareness	50.3%	34.1%	**1.47** (1.30-1.67)	*
Passenger Distraction	16.6%	8.3%	**2.00** (1.51-2.64)	*
Distraction in the Vehicle	25.3%	11.4%	**2.08** (1.52-2.84)	*
At Least One Passenger	38.5%	26.3%	**1.46** (1.18-1.81)	*
BAC (>0.01)	0.7%	4.1%	**0.16** (0.03-0.84)	*

* - Statistically significant result (α = 0.05).

Table 4. Risk ratios of a pre-crash event for teen drivers engaged in pre-crash behaviors relative to teens not engaged in the particular driving behavior.

	Distractions				Inappropriate Driving			
Pre-Crash Classification	**Present**	**Not Present**	**RR** (95% CI)		**Present**	**Not Present**	**RR** (95% CI)	
Control Loss	5.2%	9.6%	**0.55** (0.20-1.49)		8.6%	7.9%	**1.08** (0.51-2.29)	
Road Departure	32.4%	18.4%	**1.76** (1.23-2.52)	*	35.3%	19.4%	**1.87** (1.32-2.50)	*
Pedestrian / Cyclist / Animal / Object in Road	2.4%	0.7%	**3.29** (1.74-6.25)	*	0.1%	1.7%	**0.03** (0.00-0.52)	*
Rear-End	16.9%	11.8%	**1.43** (0.53-3.88)		7.3%	15.5%	**0.47** (0.20-1.11)	
Opposite Direction	2.8%	3.2%	**0.88** (0.19-4.12)		6.1%	2.1%	**2.96** (0.66-13.2)	
Event Resulting from Another Vehicle's Actions	3.2%	2.7%	**1.18** (0.54-2.61)		0.2%	3.7%	**0.05** (0.00-0.69)	*
Same Direction / Merging	3.6%	2.9%	**1.24** (0.29-5.25)		5.8%	2.3%	**2.54** (0.86-7.47)	
Intersection Turning / Cross Paths	32.9%	48.6%	**0.68** (0.52-0.88)	*	35.9%	45.5%	**0.79** (0.41-1.51)	
Other	0.6%	2.1%	**0.31** (0.08-1.23)		0.8%	1.9%	**0.43** (0.18-1.03)	

	Passengers				Inadequate Awareness			
Pre-Crash Classification	**Present**	**Not Present**	**RR** (95% CI)		**Present**	**Not Present**	**RR** (95% CI)	
Control Loss	12.0%	5.6%	**2.13** (1.08-4.20)	*	0.6%	15.6%	**0.04** (0.01-0.22)	*
Road Departure	21.3%	24.5%	**0.87** (0.60-1.25)		6.6%	40.1%	**0.17** (0.12-0.24)	*
Person / Animal / Object in Road	0.4%	1.9%	**0.20** (0.01-4.17)		0.1%	2.5%	**0.04** (0.00-0.71)	*
Rear-End	11.3%	15.0%	**0.75** (0.39-1.45)		21.2%	5.8%	**3.67** (1.53-8.83)	*
Opposite Direction	2.7%	3.3%	**0.82** (0.28-2.42)		1.0%	5.2%	**0.18** (0.05-0.76)	*
Other Vehicle's Actions	3.8%	2.2%	**1.68** (0.69-4.09)		1.2%	5.6%	**0.02** (0.00-0.15)	*
Same Direction / Merging	3.4%	2.9%	**1.17** (0.28-4.95)		3.2%	3.0%	**1.07** (0.40-2.87)	
Intersection Turning / Cross Paths	43.7%	42.9%	**1.02** (0.82-1.26)		66.7%	19.4%	**3.43** (2.31-5.17)	*
Other	1.5%	1.7%	**0.90** (0.37-2.16)		0.4%	2.8%	**0.14** (0.03-0.60)	*

Table 3 shows that distractions were 1.7 times more likely to be present in a teen driver crash as compared to an adult driver crash. The risk of a crash when driving with a passenger was shown to be about one and a half times greater for teen drivers as compared to adults. The five factors most frequently associated with teen driver crashes in which the teen was distracted, driving inappropriately, or inadequately aware of their driving environment are given in Figure 1. The values express the representation of each factor within each behavioral category. For example, passenger distractions were present in 48% of all distracted teen driver crashes. Specific crash causation factors were combined to create the crash factors listed. For example, passenger distractions combined conversing with a passenger or looking at a passenger in the vehicle. Internal and external distractions included any object or person that had the attention of the driver prior to the crash. Phone use included dialing or talking on a phone while driving. Illegal turns included turning from the wrong lane or illegal U-turns. Proceeding without awareness includes turning while visibility is limited or proceeding without enough vehicle clearance.

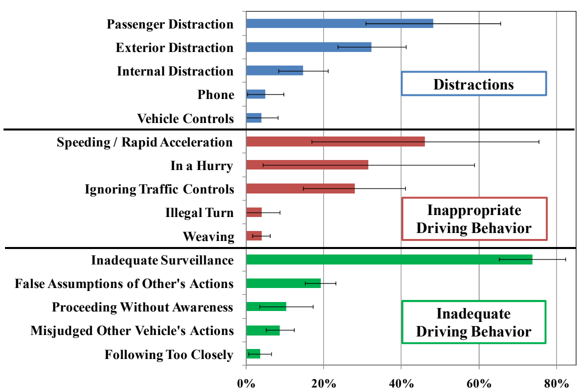


Figure 1. Top five crash factors given as the percentage of all distracted driver crashes, inappropriate driving crashes, and inadequate awareness crashes for teen drivers.

Inappropriate driving was 1.8 times more likely to have been a factor in a teen driver crash when compared to adults. This included a significant increase in crash risk from aggressive acts and being in a hurry. Speeding, rapid acceleration, and being in a hurry were the most frequently cited behaviors for teens who crashed while driving inappropriately. Also, inadequate awareness was one and a half times more likely to be a factor in teen driver crashes as compared to adult drivers. Inadequate surveillance was by far the most prevalent factor in crashes that involved inadequate driving behaviors in teen driver crashes.

As shown in Table 4, in teen driver crashes where inadequate driving awareness was cited, the risk of a rear-end crashes was almost four times as high as compared to teen driver crashes where this was not listed as a factor. Furthermore, inappropriate driving behavior resulted in almost twice the likelihood of a control loss crash as compared to teen driver crashes where this factor was not reported. Teen driver crashes with pre-crash distractions were 1.76 times more likely to result from road departures than for those without a pre-crash distraction and over three times as likely to result from an obstruction in the road. Interestingly, teen driver crashes with passengers were twice as likely to have resulted from a control loss as compared to teen drivers without passengers.

DISCUSSION

This study has identified events and behaviors that are represented more frequently in teen driver crashes, relative to adult driver crashes. The study has shown that teen drivers continue to be deficient in their driving awareness and abilities, relative to adult drivers, despite the inclusion of GDL components in every state's licensing process. Many studies published prior to GDL implementation presented these same, teen-specific factors as the root causes for increased teen crash and fatality risk. Often these studies were performed with the stated goal of encouraging reform in the licensing procedures, which led to the acceptance of GDL programs in the United States. In the years that followed, a number of individual state GDL programs have been analyzed to determine their effectiveness for reducing teen crash and fatality rates. However, to date, the existing research does not provide a national perspective on remaining teen crash causation factors. This is the first national study to focus on the residual factors that continue to lead to a higher teen crash risk after GDL implementation.

Teen Driver Crash Risk

Teen driver crashes were more likely to result from a control loss and road departure event as compared to adults. Teens who were in a crash were also more likely to be distracted, driving inappropriately, or inadequately aware of their environment when compared to adult drivers. These characteristics reflect the lack of experience and propensity of teen drivers to engage in risky behaviors. These same characteristics were often considered as a source of the elevated teen driver crash risk prior to GDL implementation [Williams, Preusser, Ulmer, 1995; Laapotti and Keskinen, 1998; McKnight and

McKnight, 2003; McCartt, Mayhew, Braitman, 2009].

Pre-Crash Event. By far, the pre-crash event category that produced the largest number (43.2%) of teen driver crashes after GDL implementation was intersections or turning vehicles. Similarly, this was also the largest pre-crash category for adult crashes (43.8%). In contrast, 44.9% of all teen driver crashes were categorized as road departure, rear-end, or control loss crashes as compared to only 25.2% of adult crashes. Teen drivers were 2.40 (CI:1.19-4.85) times more likely to be in a control loss crash, 1.88 (CI:1.12-3.15) times more likely to be in a road departure crash, and a statistically insignificant 1.44 (CI: 0.91-2.27) times more likely to be in a rear-end crashes when compared to adult driver crashes. Each of these pre-crash events likely resulted from a lack of driving experience or lack of awareness of the road environment. Furthermore, the increased risk of road departure and control loss crashes most likely contributed to teen driver crashes being 1.64 (1.18-2.28) times more likely to be a single vehicle crash. Williams (1995) showed that teen drivers were also more susceptible to single-vehicle crashes, prior to GDL. Furthermore, it has been suggested that this propensity reflects the risk taking and inexperience of teen drivers [Williams, 2006].

Inappropriate Driving Behavior. Inappropriate driving behavior and inadequate driving awareness had previously been shown to be a factor in teen crashes more often than for adults before GDL implementation [Williams et al., 1995]. Additional pre-GDL research has indicated that these deficiencies result from the inability of the teen driver to sense when they are following too close, when they are traveling too fast, or how to recover if they drift off the road resulting in the increased crash risk for these categories [Dingus, McGehee, Manakkal, 1997; Laapotti and Keskinen, 1998; Williams, 2006]. Similarly, the results from our study shows that road departure crashes were 1.87 (CI: 1.32-2.50) times more likely in teen driver crashes with inappropriate driving as compared to those without. Inappropriate behavior includes aggressive driving, speeding, or frequently changing lanes. Laapotti and Keskinen (1998) found that young Finnish drivers had an increased risk of control loss crashes, which often lead to road departures, when driving inappropriately. Furthermore, it was noted that these inappropriate driving behaviors magnified the lack of experience when the teen driver was presented with a possible crash scenario. Thus, the teen driver's lack of experience combined with inappropriate driving behavior would further increase their crash risk. This type of behavior has often been linked to the thrill-seeking mentality of teen drivers [McKnight and McKnight, 2003; Williams, 2006]. The reason that teens engage in these behaviors has been attributed to a number of factors including peer-pressure, the way that teens prioritize risk, and as a normal function of adolescence [Spear, 2000; Keating and Halpern-Felsher, 2008]. Whatever the reason, our research shows that inappropriate driving was 1.83 (CI: 1.38-2.43) times as likely to be represented in teen driver crashes as compared to adults, indicating that these behaviors still play a significant role in teen driver crash risk after GDL implementation.

Inadequate Driving Awareness. Prior to GDL implementation, inadequate driving awareness was often cited as a common crash causation factor for teen drivers [Williams et al., 1995; Williams, 2006]. Braitman et al (2008) found that inadequate evaluation, search, and detection performance contributed to a majority of 16-year old crashes in Connecticut. In our study, inadequate surveillance was present in 74% of teen crashes where the driver was inadequately aware of their driving environment. McKnight (2003) showed that younger and less experienced teen drivers in California and Maryland had a higher crash risk when compared to older teen drivers due to lack of visual search, not watching the car ahead, driving too fast for conditions, and failure to adjust to wet roads. As shown in this study, despite GDL licensing procedures nationwide, inadequate driving awareness was still represented in 50.3% of teen driver crashes. Inadequate driving awareness was cited 1.47 (1.30-1.67) times more often in teen driver crashes as compared to adults. We also found that rear-end crashes were 3.67(CI: 1.53-8.83) times as likely to be represented in teen crashes where the driver was inadequately aware as compared to those who were not. These results indicate that driving awareness factors continue to play significant roles in teen driver crash risk after GDL.

Driver Distraction. Distractions also contributed to a significantly greater crash risk for teen drivers. In our dataset, distractions were considered a factor in 34.4% of teen crashes as compared to 19.9% of adult crashes. Of these, conversations with passengers were cited in 16% of teen crashes and represented 91% of all teen driver conversations prior to a crash event.

Cell phone use. In the NMVCSS dataset, cell phone use while driving for teen drivers played a surprisingly small role in crashes, representing less than 2% of teen driver crashes. Texting was not cited in any of our teen driver cases. Similar results were reported in a study of Connecticut 16-year olds which found that 26% of drivers were distracted prior to a crash and that 2% of the distractions were from a cell phone conversation [Braitman, Kirley, McCartt, 2008]. It is possible that the low number of cell phone conversations and lack of texting crashes reflects the effectiveness of mandates included in many GDL programs that seek to curb teen cell phone use while driving. The infrequency of cell phone use in this study may also reflect the frequency of cell phone use during the NMVCSS data collection period. Cell phone use and, to a greater extent, texting while driving has increased significantly since 2007 [Madden and Lenhart, 2009].

Driver cell phone use is widely believed to increase crash risk. The Insurance Institute for Highway Safety (2005) estimates that cell phone use can increase the risk of an injurious crash by as much as 400%. Teens are at an especially high risk for crashes while using a cell phone which has led to the introduction of cell phone restriction for novice drivers in 25 states and Washington, D.C. as of May, 2010 [IIHS, 2010b].

Passengers. In this study, the most significant distraction for teen drivers was the presence of passengers. In teen driver crashes, the presence of a passenger was represented 1.46 (CI: 1.18-1.81) times more often than for adult drivers. As shown by Farrow (1987), there is a strong association between the presence of peers and inappropriate driving behaviors for teen drivers. Therefore, the combination of a lack of experience along with the distractions and inappropriate driving behaviors associated with passengers presents a troublesome combination of risk factors for teen drivers. This type of association is the reason that many states have imposed restrictions on the number of passengers or the familial relationship of passengers for teen drivers. At the time NMVCCS data collection began (7/3/2005), 29 states had implemented restrictions on passengers for teen drivers and another 11 instituted passenger restrictions during the data collection period (7/3/2005-12/31-2007) [IIHS, 2010a]. Nonetheless, passenger distractions (i.e. talking to or looking at a passenger) were present in 20% of teen crashes compared to 9% of adult crashes, resulting in significantly greater crash risk ratio associated with the presence of passengers in teen driver vehicles. Furthermore, control loss crashes were represented 2.13 times more frequently in teen driver crashes with passengers as compared to those without. These results suggest that limiting the number of passengers or the familial relationship of passengers for teen drivers may not be sufficient in the early stages of licensure.

Alcohol. Alcohol is often cited as a significant factor in teen driver crashes. Our study found that alcohol was a significantly less frequent factor in teen crashes than in adult crashes. However, this is a result of the infrequency of drinking and driving for teens, relative to adults, and less of a reflection on the risk of a crash for those who do drink and drive. In fact, Mayhew (1986) found that teen drivers drink and drive less frequently than adults but have higher crash risk when they do. Also, the NMVCCS dataset did not include crashes that occurred between midnight and 6am. Teens that drink and drive may do so at night. These teens would not be included in this analysis.

Night Driving. Nighttime driving has been identified as a high-risk driving scenario for teen drivers, resulting in an increased crash risk and fatality risk [Williams et al., 1995; Doherty, 1997; Williams, 2003.] As a result, most states have instituted restrictions on the hours that GDL drivers can be on the road. However, the NMVCCS database only included crashes that occurred between 6:00am – 11:59pm. As a result, an evaluation of the crash risk associated with nighttime driving for teens was not possible in this study.

Implication of Results

Many of the factors and pre-crash categories that have been associated with an increase in teen driver crash risk are highly dependent on driver experience and awareness, namely road departure and control loss crashes. Deery (1999) reported that teen drivers are quite adept at acquiring basic driving skills. However, their limited experience does not allow them to develop the high-order cognitive abilities required to safely address many complex driving situations. Furthermore, Brown and Groeger (1988) reported that risk perception is controlled by two inputs: 1) information on the potential hazards and 2) information on a person's abilities to handle these hazards. A recent study examined the driving abilities of Finnish and Dutch novice drivers and found that 30-40% of novice drivers over estimate their own driving abilities [Mynttinen, Sundstrom, Vissers, 2009].

One interpretation of our findings is that GDL has reduced teen crashes by limiting exposure rather than by providing the appropriate training for teens. Fohr et al (2005) suggests the real effectiveness of GDL may be in its ability to limit exposure to risky driving situations while subject to the regulations; Fohr et al suggested that GDL does not necessarily produce safer or more capable drivers. Our study has shown that despite the structured training and driving practice provided by GDL, the inability of many teens to assess the presence of potential hazards and the inability to adequately assess their own driving capabilities continues to be the source of the increased crash risk. However, because NMVCSS collected only post-GDL data, our study should not be interpreted as providing a definitive answer to this question. One possible explanation for our findings, for example, would be that GDL has been very effective for most teens, but has been ineffective for some teen sub-groups because of learning differences. We hope that the worrisome findings of our study will motivate a follow-up investigation of this very important question using an alternative dataset.

Our study has shown that many of the experience and skill related factors which led to pre-GDL crashes continue to contribute to an increased crash risk for teen drivers, despite a reduction in crash rate after GDL implementation. As highlighted by Ferguson (2003), GDL has components that at least partially address these crash factors that disproportionately lead to an increased teen crash risk. However, there are enhancements that can be explored to address more of the inexperience and maturity problems that continue to play significant roles in the elevated teen crash risk. These include increased penalties resulting from the most frequent inappropriate driving behaviors such as speeding.

Another enhancement would be secondary driving classes that teach risk awareness and vehicle control after the basic driving skills have been mastered. In particular these programs should focus on the most common inadequate driving behaviors such as inadequate surveillance and judging the actions of other vehicles. Also, these programs could stress the consequences of inappropriate driving behavior, specifically the factors that are shown in this study to be particularly detrimental for teen drivers, such as the increased risk of road departure crashes. Secondary training programs have been implemented in GDL programs abroad. However, the successes of these enhancements are unclear and require further study before they are incorporated into GDL regulation in the United States [Ferguson, 2003].

It is possible that an increase in the minimum number of logged hours in the supervised driving stage of licensure would provide more contextual experience for the teen driver and may reduce the influence of these factors. Before the NMVCSS data collection period (7/3/2005), 37 states had requirements for a minimum number of supervised driving hours, During the NMVCSS data collection period, another five states instituted minimum practice requirements. However, the minimum requirements by state ranged from 12-100 hours. Furthermore, five of the states allowed exemptions from this rule if the driver had taken a driver's training course [IIHS, 2010a]. These exceptions were allowed despite evidence that discounting the supervised driving requirements with the successful completion of a driver's training course does not make up for the safety benefits of supervised driving [Mayhew, Simpson, Williams, 1998].

Finally passenger distractions continue to be a significant factor in teen driver crashes. States should continue to limit the presence of passengers to reduce these effects, and should strongly consider a ban on all passengers traveling with GDL drivers. Prior to the data collection period for this dataset, seven (7) states and Washington, D.C. had banned passengers (with the exception of parents) for provisionally licensed drivers for at least the first 90 days of licensure. While these same districts have since updated these policies, no other state has instituted a similar ban on passengers [IIHS, 2010a].

Significance Reporting and Table Structure

In many instances the relative risks comparing the risk of teen drivers being involved in a particular crash type or resulting from a particular driving situation may express a significant result (i.e. the confidence intervals do not include a value of one) when normalized to adult drivers, but a similar comparison of crash mode percentages shown in the appendix for teen and adult drivershave over-lapping confidence intervals, suggesting an insignificant result. This is the result of the different methods used to compute the confidence intervals. The confidence intervals for the relative risk estimates reflect the variances within the strata for all cases included in the analysis (i.e. teen <u>and</u> adult drivers) while the confidence intervals for the proportions (i.e. percentages) use the variance within the strata for each sub-population (i.e. teen <u>or</u> adult drivers only). However, as a result of the differences in the confidence interval determination methods, slightly different conclusions can be drawn from each. The relative risk confidence intervals evaluate how well the point estimate reflects the actual risk of a teen driver crash when normalized to adult driver crashes. On the other hand, the confidence intervals from the proportions express the relative frequency of a particular crash situation or behavior, but only within a given sub-population.

Limitations

This research has presented a data-driven assessment of some of the remaining crash causation behaviors and scenarios that continue to contribute to a greater crash risk for teen drivers after GDL implementation. This is not meant, however, to discount the findings of other studies that have noted significant reductions in teen driver crash rates associated with GDL implementation. Instead, it is a reminder that teen drivers have different abilities and susceptibilities, when compared to more experienced drivers. Furthermore, this study highlights the need for continuing adjustment and enhancement of current GDL regulation. Specifically, it is possible that current GDL laws are less effective at addressing the experience issues that continue to lead to teen crashes as well as the influence of distractions, namely passengers, on teen driver crash risk.

The definition of "teen drivers" as those who are 16-18 years old is meant to focus on the drivers who are most directly influenced by GDL regulation. In most states, GDL regulation covers 16-17 year old novice drivers and can extend into the 18 year old population as well. However, the "teen" group will include some drivers who are not under GDL regulation, but have most likely graduated from a GDL program. Ideally, it would be beneficial to perform an age-specific analysis to determine general trends as they relate to age. However, there were insufficient cases to conduct this analysis. Similarly, licensure date and licensing status were not available in the NMVCCS dataset. As a result, it was not possible to perform an analysis based on license type, i.e. learner's permit, provisional license, or basic license.

Another limitation is that this national study aggregates all cases from NMVCCS regardless of the state in which the crash occurred. GDL regulations can vary significantly by state. Based on the NMVCCS survey structure, cases for this dataset were selected from many, but not all states. This may affect the distributions expressed in the results. However, the primary sampling units for the NMVCCS dataset are provided in the coding manual, making it possible to know the states from which data was collected [Bellis and Page, 2008]. Of the 17 states sampled to create the NMVCCS dataset, it was found that the distributions of regulations were similar to what were seen nationally at the time of data collection. Of the 17 states, 11 had passenger restrictions prior to data collection, 2 instituted them during data collection and 4 had none during this time period. Similarly, 14 states implemented nighttime driving restriction prior to data collection, 1 instituted them during data collection and 2 had none during this time period. Finally, 13 had a minimum requirement for the number of logged hours in permit license stage prior to data collection and 4 had none during this time period. However, 3 of the states waived the requirement if the teen driver completed a driver training course. In all, the logged hour requirements for the 17 states ranged from 20-60 hours [IIHS, 2010a].

The NMVCCS dataset does not contain crashes that occurred between 12-6am. This also serves as a limitation. Based on an analysis of the FARS database over the same time period, it was found that 21% of all fatalities involving teen drivers occurred between these hours. Therefore, our study is missing significant information regarding the behaviors and events that lead to teen driver crashes at night - a time when teens are known to have an even higher crash risk.

Finally, the method for computing risk ratios assumes that teen and adult drivers were exposed to the same driving environment. However, systemic biases could have existed that would have resulted from differences in the teen and adult driving populations. For example, adults may drive later model vehicles with advanced countermeasures, e.g. electronic stability control which would result in fewer road departure crashes. Other biases may result from different vehicle maintenance priorities or roadway travel differences between teens and adults. In the context of the current study, our methods were utilized with assumptions. These include 1) the crash rates of teen and adult drivers are independent and 2) any underlying systemic biases are negligible.

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CONCLUSION

Despite marked reductions in the number of teen crashes after the implementation of GDL, teen drivers are still susceptible to higher crash rates resulting from specific behaviors and pre-crash scenarios. However, the identification of these teen driver crash causation factors may serve to guide future enhancements to current GDL regulations. Overall, the results show that 1) intra-vehicle distractions, namely passengers, 2) inappropriate and inadequate driving, 3) control loss, and 4) road departures continue to create a greater teen crash risk when compared to adult driver crashes after GDL implementation. Based on the findings of this study, it is recommended that the states consider a ban on passengers in the first months of unsupervised driving. Also, this study has shown evidence to motivate further investigation into the benefits of secondary driving courses. These courses could supplement current GDL regulation with training that addresses the pre-crash events and behaviors that are outlined in this study and help to produce a more adept teen driver population in the United States.

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Appendix. Distribution of Pre-Crash Classifications Crash Causation Factors for Teen and Adult Drivers (NMVCCS 2005-2007).

	TEEN			ADULT		
	% (95% CI)	n	n (w'td)	% (95% CI)	n	n (w'td)
Total Sample Size		**801**	**320,358**		**3,159**	**1,179,490**
Pre-Crash Classification						
Other	**1.6%**(3.0%-5.3%)	23	5,120	**4.1%**(3.0%-5.3%)	161	48,713
Control Loss	**8.1%**(11.4%-29.5%)	50	25,923	**3.4%**(2.4%-4.3%)	81	39,716
Road Departure	**23.2%**(0.0%-2.2%)	152	74,438	**12.4%**(9.7%-15.0%)	343	145,740
Pedestrian / Cyclist / Animal / Object in Road	**1.3%**(12.0%-15.9%)	6	4,184	**0.8%**(0.2%-1.4%)	28	9,394
Rear-End	**13.6%**(2.1%-5.6%)	89	43,426	**9.4%**(7.2%-11.6%)	319	111,184
Opposite Direction	**3.1%**(3.1%-5.5%)	26	9,777	**7.9%**(6.8%-8.9%)	170	92,592
Event Resulting from Another Vehicle's Actions	**2.8%**(1.9%-5.2%)	40	9,084	**12.3%**(10.6%-14.1%)	362	145,471
Same Direction / Merging	**3.1%**(31.1%-49.6%)	33	9,977	**6.0%**(4.1%-7.8%)	216	70,296
Intersection Turning / Cross Paths	**43.2%**(2.3%-5.6%)	382	138,430	**43.8%**(38.5%-49.1%)	1,479	516,384
Crash Causation Factors						
Distracted Driver Crashes	**34.4%**(25.5%-43.3%)	282	110,046	**19.9 %**(16.6%-23.2%)	687	234,624
Conversing	**18.0%**(13.2%-22.7%)	**162**	**57,503**	**9.4%**(6.6%-12.2%)	**344**	**110,932**
Conversing with passenger	**91.0%**(83.3%-98.7%)	144	52,334	**82.9%**(72.6%-93.3%)	289	92,008
Talking on phone	**9.0%**(1.3%-16.7%)	18	5,169	**14.1%**(5.3%-22.8%)	51	15,599
Talking on CB radio	**0.0%**(0.0%-0.0%)	0	0	**0.6%**(0.0%-1.7%)	1	611
Other	**0.1%**(0.0%-0.1%)	0	0	**2.5%**(0.0%-7.2%)	3	2,713
Other Distraction	**13.1%**(3.6%-22.7%)	**81**	**42,109**	**5.3%**(3.5%-7.1%)	**176**	**62,460**
Looking at Other Occ	**29.9%**(24.8%-34.9%)	21	12,585	**19.4%**(3.9%-34.9%)	27	12,139
Dialing Phone	**1.2%**(0.0%-3.4%)	3	513	**4.9%**(0.0%-11.0%)	12	3,076
Adjusting Radio	**8.5%**(0.0%-21.4%)	14	3,585	**2.9%**(0.0%-6.5%)	7	1,815
Adjusting Vehicle Controls	**1.7%**(0.0%-3.7%)	4	695	**2.1%**(0.0%-4.8%)	4	1,283
Retrieving Object	**19.7%**(13.7%-25.7%)	17	8,285	**18.3%**(11.0%-25.6%)	37	11,442
Eating / Drinking	**13.0%**(0.3%-25.6%)	7	5,472	**13.1%**(3.6%-22.7%)	24	8,203
Smoking	**5.6%**(0.0%-13.6%)	2	2,350	**6.3%**(0.1%-12.5%)	11	3,940
Reading Map/Directions/Newspaper	**0.0%**(0.0%-0.0%)	0	0	**6.3%**(1.1%-11.4%)	14	3,920
Focused on Internal Object	**27.8%**(17.4%-38.3%)	17	11,720	**26.3%**(17.8%-34.8%)	39	16,413
Texting	**0.0%**(0.0%-0.0%)	0	0	**0.4%**(0.0%-1.1%)	1	228
Exterior Factor	**11.1%**(6.7%-15.6%)	**93**	**35,579**	**7.28%**(5.1%-9.5%)	**257**	**85,855**
Looking at Crash	**0.6%**(0.0%-1.8%)	1	203	**1.9%**(0.0%-5.0%)	4	1,666
Looking at Traffic	**35.7%**(8.7%-62.7%)	58	12,699	**48.0%**(38.8%-57.1%)	149	41,169
Looking for Address	**2.8%**(0.0%-6.9%)	4	1,000	**2.8%**(0.0%-5.7%)	8	2,361
Looking at Outside Person	**1.7%**(0.0%-4.0%)	3	607	**11.7%**(0.0%-23.6%)	23	10,041
Looking at Building	**3.9%**(0.0%-11.9%)	3	1,371	**5.7%**(0.1%-11.3%)	13	4,899
Unspecified Outside Focus	**32.7%**(2.2%-63.2%)	10	11,630	**14.8%**(3.8%-25.9%)	16	12,744
Other	**15.9%**(5.7%-26.0%)	13	5,644	**12.3%**(5.3%-19.3%)	37	10,548
Looking At Animal	**7.0%**(0.0%-20.2%)	2	2,479	**2.8%**(0.2%-5.5%)	7	2,427

Inappropriate Driving Behavior	**24.1%**(19.7%-28.5%)	179	77,112	**13.1%**(10.5%-15.8%)	479	154,855
Illegal Maneuver	**8.1%**(3.8%-10.2%)	**146**	**47,746**	**7.9%**(5.6%-12.4%)	**287**	**93,130**
Crossed Full Barrier Lines While Passing	**4.9%**(0.0%-10.2%)	5	1,144	**5.3%**(0.0%-11.5%)	4	4,936
Passed On Right	**0.0%**(0.0%-0.0%)	0	0	**1.0%**(0.0%-2.8%)	4	963
Turned From Wrong Lane	**9.6%**(0.0%-24.1%)	4	2,248	**1.6%**(0.4%-2.7%)	12	1,458
Initiated Illegal U-Turn	**3.6%**(1.1%-6.1%)	3	846	**2.4%**(0.5%-4.2%)	13	2,192
Failed To Obey Traffic Control Device	**77.3%**(65.4%-89.3%)	65	18,119	**78.1%**(69.0%-87.1%)	222	72,706
Drove Wrong Way On Roadway	**5.5%**(0.0%-13.0%)	3	1,292	**1.1 %**(0.0%-2.3%)	7	993
Other Illegal Maneuver	**1.9%**(0.0%-4.3%)	3	444	**10.6%**(5.0%-19.3%)	25	9,882
Aggressive Act	**10.6%**(3.7%-17.5%)	**137**	**62,714**	**3.42%**(2.0%-4.9%)	**119**	**40,392**
Speeding	**83.1%**(70.3%-96.0%)	65	31,233	**55.6%**(29.1%-82.0%)	49	22,438
Tailgating	**1.2%**(0.0%-3.6%)	3	457	**0.6%**(0.1%-1.1%)	3	246
Rapid/Frequent Lane Changes/Weaving	**8.0%**(1.3%-14.6%)	15	2,993	**20.2%**(0.0%-41.1%)	24	8,165
Ignoring Traffic Control Devices	**9.2%**(0.0%-22.8%)	11	3,454	**13.7%**(4.6%-22.9%)	27	5,536
Accelerating Rapidly From Stop	**12.5%**(0.4%-24.6%)	6	4,705	**0.8%**(0.0%-2.2%)	4	317
Stopping Suddenly	**0.0%**(0.0%-0.0%)	0	0	**0.2%**(0.0%-0.5%)	1	65
Honking Horn	**0.0%**(0.0%-0.0%)	0	0	**0.4%**(0.0%-1.3%)	1	151
Flashing Lights	**0.0%**(0.0%-0.0%)	0	0	**0.8%**(0.4%-1.3%)	1	337
Obscene Gestures	**0.0%**(0.0%-0.0%)	0	0	**0.4%**(0.0%-1.3%)	1	167
Obstructing The Paths Of Others	**0.0%**(0.0%-0.0%)	0	0	**0.5%**(0.0%-1.7%)	1	210
Other	**1.6%**(0.0%-4.4%)	5	608	**6.8%**(0.0%-13.8%)	7	2,761
In a Hurry	**7.6%**(1.6%-13.6%)	**58**	**24,293**	**3.9%**(2.9%-4.9%)	**153**	**46,189**
Inadequate Awareness	**50.3%**(46.1%-54.9%)	415	161,284	**34.1%**(30.7%-37.6%)	1,248	402,720
Inadequate Surveillance	**73.7%**(65.1%-82.3%)	275	118,905	**40.7%**(33.6%-47.7%)	487	163,755
Other Driver Recognition Factors	**16.0%**(8.5%-23.5%)	62	25,807	**6.0%**(3.3%-8.6%)	69	23,999
Following Too Closely	**3.6%**(0.7%-6.5%)	26	5,750	**5.5%**(2.8%-8.1%)	63	21,965
Misjudged Vehicles Direction Of Approach	**8.7%**(5.1%-12.3%)	46	14,025	**5.7%**(4.0%-7.5%)	82	23,088
False Assumption Of Other Road User's Actions	**19.2%**(15.2%-23.1%)	97	30,899	**24.3%**(19.2%-29.5%)	322	98,088
Other Driver Decision Factor	**17.7%**(12.5%-22.9%)	61	28,521	**17.8%**(13.5%-22.1%)	225	71,824
			Other Factors and Distributions			
Passenger Distraction	**16.6%**(12.1%-21.0%)	145	53,029	**8.3%**(6.7%-9.9%)	292	97,811
At Least One Passenger	**38.5%**(29.2%-47.7%)	340	123,303	**26.3%**(23.4%-29.1%)	935	310,089
Single Vehicle Crash	**18.7%**(11.3%-26.0%)	117	59,752	**11.4%**(8.8%-14.0%)	298	134,399
Weather	**10.1%**(5.5%-14.6%)	87	32,208	**10.9%**(8.5%-29.1%)	291	128,224
BAC (>0.01)	**0.7%**(0.0%-1.7%)	4	2,122	**4.1%**(2.4%-5.8%)	106	7,490
Speed Limit (km/h)	**65.9**(62.5-69.3)	780	315,817	**68.9**(64.4-72.4)	3,064	1,153,890
Gender (% Male)	**51.5%**(45.8%-57.3%)	801	320,358	**57.5%**(51.4%-63.6%)	3,159	1,179,491
Vehicle Type (% Car)	**66.9%**(60.9%-72.8%)	801	320,358	**43.5%**(40.3%-46.7%)	3,159	1,179,491