The Effects of Distractions and Driver's Age on the Type of Crash and the Injury Severity Sustained by Occupants Involved in a Crash

by

Zishu Liu

A thesis submitted in conformity with the requirements
for the degree of Master of Applied Science

Department of Mechanical and Industrial Engineering
University of Toronto

The Effects of Distractions and Driver's age on the Type of Crash and the Injury Severity Sustained by Occupants Involved in a Crash

Zishu Liu

Master of Applied Science

Department of Mechanical and Industrial Engineering
University of Toronto

2011

Abstract

This thesis investigates the associations between crash outcomes, the existence and type of driver distraction as well as driver's age. Only a limited number of studies have investigated driver distraction as it relates to crash outcomes. Moreover, these studies were limited to specific demographics (i.e., young drivers and police officers). This thesis addresses a gap in the literature by considering and comparing drivers of all ages. The crash outcomes considered in this thesis consist of the type of crash as well as the injury severity sustained by occupants (i.e., passengers and drivers) involved in the crash. An ordered logit model was built to predict the likelihood of severe injuries and a multinomial model was developed to predict the likelihood that a driver will be involved in one of three common crash types: singular, angular, and rear-end. The models were built on a national crash database: U.S. General Estimates System (2003 to 2008). In these models, various factors (e.g., weather, driver's gender, and speeding) have been statistically controlled for, but the main focus was on the interaction of driver's age and distraction type. The findings of this thesis have implications for policy making and prioritizing capabilities of distraction-related safety systems.

Acknowledgments

First and foremost, I offer my sincerest gratitude to my supervisor, Professor Birsen Donmez, who has supported me throughout my thesis with her patience and knowledge whilst allowing me the room to work in my own way. I attribute the completion of my graduate study to her encouragement and effort. Without her, this thesis would not have been completed or written. One simply could not wish for a better or friendlier supervisor.

I would like to thank my wife, Ruosi Sun, who has supported me in the past eight years, and will continue doing so in the future. The joy and happiness she brings to me shaped my mind and heart. Being married with her makes me a better person.

My parents, Weimin Yang and Chunbo Liu, are on my back all the time. I will remember the speech they gave at my wedding. Home is my harbour, and they defined the best home I could possibly imagine.

Last but not least, my friends and colleagues in HFASt and CEL, Maryam, Adam, Kevin, Tony, Patrick, Joshua, Arsham, and Nathan, thanks for the help you have given me during my stay as well as those intellectually-stimulating conversations inspired my study and work. Special thanks are given to Professor Greg Jamieson, who broadened my view of research topics and methods.

Table of Contents

List of Tables

List of Figures

Chapter 1
Introduction

1.1 Driver Distraction

1.1.1 Definitions

Broadly, driver distraction can be defined as “the diminished attention of the driver to the driving task” (Donmez, Boyle, & Lee, 2006). Attention may be diminished due to an external source (e.g., using a cell phone) or internally (e.g., being lost in thought). Some definitions focus on the former, i.e., they define driver distraction as a consequence of external sources. For example, Stutts et al. (2001) state that distraction occurs when a driver is delayed in recognizing information necessary to drive safely because some event, activity, object, or person within or outside the vehicle compels the driver to shift attention away from the driving task. Within the broader definition, drowsiness or fatigue can also be seen as a special case of distraction, as it leads to progressive withdrawal of attention from the road and traffic demands (Williamson, 2009).

This thesis adopts the broader definition of driver distraction to assess associations between various sources of distractions and crash outcomes, while differentiating between external and internal sources. Ranney (2008) proposed four major categories of distraction sources: visual, auditory, biomechanical, and cognitive. Most distractions are a combination of these four categories, so it is useful and practical to study certain tasks that drivers engage in rather than the more abstract categories (Neyens & Boyle, 2007). The tasks induced by external sources, which are commonly observed and are investigated in this thesis, are as follows: talking on a cell phone, dialling/texting on a cell phone, interacting with in-vehicle technologies, eating and drinking, talking with passengers, and looking at objects outside of the vehicle. The granularity of these tasks is dictated by the level of detail recorded for police-reported crashes, which this thesis utilizes. As for internal sources, this thesis investigates drowsiness and fatigue as well as lost in thought and looked but did not see. Lost in thought and looked but did not see are referred to as inattention in the police reports; they are also often referred to as cognitive distraction in the literature (Liu & Donmez, 2011; Neyens & Boyle, 2007). Both terms are somewhat misleading given that inattention can be caused by a broad set of sources. Similarly, most, if not all, distractions lead to a cognitive interference. This thesis adopts the term “inattention” to maintain consistency with police reports.

1.1.2 Human Behaviours Contributing to Crash Risks

Human error is estimated to be the sole cause in 57% of all traffic crashes and a contributing factor in over 90% of them (Treat et al., 1979). Specifically, inappropriate speed choice, gap acceptance decisions, close following distances, and improper visual scanning behaviours have been identified to increase crash risks (Cooper & Zheng, 2002; Heino, Van der Molen, & Wilde, 1996; Kloeden, 2001; Leung & Starmer, 2005; Neyens & Boyle, 2007; Owsley & McGwin Jr, 2010; Poole & Ball, 2005). These hazardous behaviours may stem from conscious choices resulting from risk taking tendencies (e.g., sensation seeking, willingness to engage in distracting activities) and/or from an inability to assess roadway demands appropriately due to factors such as inexperience or perceptual/cognitive saturation. Driver distraction can contribute to crash risks by facilitating inappropriate behaviours due to a conscious decision to engage in distracting activities and/or the resulting perceptual/cognitive demands.

Kloeden et al. (2001) estimated that in a 60 km/h speed limit zone, the risk of being involved in a fatal crash doubles with each 5 km/h increase in travelling speed above 60 km/h. While speeding has been tied to an increased likelihood of severe crashes, maintaining close following distances is suggested to increase the risk of rear-end crashes (Neyens & Boyle, 2007). Although no explicit links to actual crash risks or outcomes have been established, closer following distance and shorter gap acceptance are considered to be riskier and are used as risk measures in previous studies (Cooper & Zheng, 2002; Heino, et al., 1996; Leung & Starmer, 2005). Inappropriate scanning behaviours have also been suggested to increase crash risks (Owsley & McGwin Jr, 2010). Longer fixations to internal or external objects, less frequent saccades, and maintaining a narrow field of view indicate that the driver may not be attending to safety relevant information in the environment (Poole & Ball, 2005).

These risky behaviours appear to manifest in varying degrees across different age groups. For example, teen drivers, due to their inexperience, often fail to scan further ahead on the road (Harrison, 1997). Differences have also been found across age groups regarding choices of speed, following distance, and gap acceptance (Wasielewski, 1984). Differences in these behaviours combined with varying information processing capabilities lead to different crash risks and crash outcomes for different age groups. The relationship between crash involvement and driver age is a U-shaped function, where rates are higher for older and younger drivers (Massie, Campbell, & Williams, 1995). For example, younger drivers drive more at-risk than mid-age or older drivers in terms of faster speeds, closer following distances, less efficient visual scanning behaviours, and higher levels of distraction involvement (Boyce & Geller, 2002), whereas older drivers have a diminished ability to respond to hazardous situations due to age related degradation in perception, cognition, and reaction (Chaparro & Alton, 2000; DeLucia, Kaiser, Bush, Meyer, & Sweet, 2003; Strayer & Drews, 2004). Given the inherent variation across age groups in behaviour and performance, and the research gaps that will be discussed in the following sections, this thesis will be the first to investigate the associations between crash outcomes and distraction – age interaction.

1.1.3 The Prevalence of Driver Distraction in Crashes

With the increasing sophistication of entertainment and driving assistance technologies on board, drivers are exposed to more distraction sources than before. Performing non-driving-related tasks imposed by these sources can divert driver's attention away from activities critical for safe driving (Lee, Young, & Regan, 2009). Even in the years preceding the widespread use of complex technologies in vehicles, between 13 and 50 percent of crashes are attributed to driver distraction. The estimated consequences are as many as 10,000 lives lost and as much as $40 billion in damages each year (Stutts, et al., 2001; Sussman, Bishop, Madnick, & Walter, 1985; Wang, Knipling, & Goodman, 1996).

Reason's (1990) accident causation model suggests that an accident cannot be attributed to one simple cause. Instead, it occurs due to a chain of related events. Although the cause of a crash cannot be summed up by looking at a single factor (e.g., human error, environmental condition, or vehicle problem), the existence of these specific factors can be informative. A large naturalistic truck study identified driver distraction to be the immediate reason in 17% of crashes (Starnes, 2006). In the largest naturalistic study of passenger vehicles to date, the 100-car naturalistic study where 109 drivers were monitored, 80% of 69 crashes and 65% of 761 near-crashes that were recorded involved observable distractions (including eyes-off-road and conversing on the phone or with passengers) within three seconds before the moment of contact; whereas prior estimates had been in the range of 25% (Dingus et al., 2006).

On the contrary to the frequent prevalence of distraction in pre-crash moments, it appears that distraction engagement in general is much lower. For example, in a study by Stutts et al. (2005) where video cameras were installed in the vehicles of 70 drivers in North Carolina and Philadelphia (where use of hand-held phones was legal) and data were collected over a week, 34% of drivers used their cell phones while driving, but the time they spent on their cell phones was only 4 to 9% of their total driving time. In the same study, 90% of drivers adjusted their on-board radios or CDs, but the time they spent on these tasks constituted only 1.5% of their total driving time. Such contrary statistics provide additional motivation for studying these relatively low exposure activities which prevail in so many crash and near-crash events.

1.2 Crash Outcomes

This thesis focuses on crash outcomes, i.e., injury severity and type of crash, which are important aspects to consider for policy making and design of safety systems. For example, policy makers may prioritise addressing distraction types that are associated with severe injuries. Similarly, distraction mitigation system development can be guided by information obtained on the association of different distraction types and crash types.

1.2.1 Crash Injury Severity

Several studies investigated factors which influence crash injury severities (Eluru & Bhat, 2007; Farmer, Braver, & Mitter, 1997; Huelke & Compton, 1995; Kim, Nitz, Richardson, & Li, 1995; Kockelman & Kweon, 2002). These factors include speed, seatbelt use, environmental conditions, vehicle types, crash types, as well as drivers’ and other occupants’ characteristics. Specifically, environmental conditions such as daylight, rural roads, and curves have been found to increase injury severities. On the other hand, crashes in bad weather, on the highway, and at intersections are associated with a decrease in severe injuries (Massie, et al., 1995; Muelleman, Wadman, Tran, Ullrich, & Anderson, 2007). Moreover, if a young driver is male or is drunk then the crash results in more severe injuries (Neyens & Boyle, 2008). However, male drivers themselves sustain less severe injuries than female drivers (Kockelman & Kweon, 2002). Proper use of seatbelt and sitting at the back decrease an individual's injury severity (Eluru & Bhat, 2007; Farmer, et al., 1997; Huelke & Compton, 1995; Kim, et al., 1995; Kockelman & Kweon, 2002). Female and old victims sustain more severe injuries (Kim, et al., 1995). Not surprisingly, occupants of bigger and heavier vehicles, i.e., SUVs and trucks, sustain less severe injuries (Farmer, et al., 1997; Kockelman & Kweon, 2002).

Drowsiness/fatigue also appears to influence injury severities. In the U.S., from 2005 to 2009, drowsiness was a factor in 1.4% of all crashes, whereas it was a factor in 2.5% of the fatal ones. This descriptive statistic indicates that drowsy driving appears to be a contributing factor in larger proportion of fatal crashes than non-fatal crashes (NHTSA, 2011).

Speeding has also been found to be a significant factor affecting crash injury severities. It is reported that an above speed limit crash is associated with more severe injuries than a below speed limit crash (Farmer, et al., 1997; Kockelman & Kweon, 2002). The police reports, which are the data sources of previously mentioned studies as well as this thesis, only capture if a driver was speeding or not. These reports do not include the nominal speed values, which is a general limitation of police-reported crash data analysis. Some of the findings presented above (e.g., decreased injury severity associated with bad weather) may in part be explained by the nominal speeds maintained before a crash.

Speed and type of crash affect injury severity through force and area of impact (Otte et al., 2009). The force of impact in a rear-end crash would be expected to be smaller than that in a head-on crash because of likely smaller relative speeds between crashing objects. Therefore, even though travelling at the same speed, occupants in a rear-end crash might sustain less severe injuries than occupants of a head-on crash. In fact, Kockelman and Kweon (2002) found that after controlling for speeding among other covariates, head-on crashes are more severe than rear-end crashes. In an angular crash, people in the struck vehicle sustain more severe injuries than those in the striking vehicle (Kockelman & Kweon, 2002). The location of impact might be playing a significant role here, as vehicles have more front protections than side protections.

Limited literature investigated the associations between driver distraction and crash injury severities (Liu & Donmez, 2011; Neyens & Boyle, 2008; Zhu & Srinivasan, 2011). The results from Neyens and Boyle (2008) and Liu and Donmez (2011) suggest that distractions coming from external sources increase injury severities. However, these studies only focused on specific groups of drivers, i.e., teenage and police drivers respectively. Zhu and Srinivasan (2011) focused on truck drivers and found that distraction is a significant factor leading to severe crash injuries. Given that all three studies focused on specific populations, a study investigating the differences in the broader driver population is needed.

1.2.2 Crash Type

Non-pedestrian and non-cyclist involved crashes are generally categorized into singular, angular, sideswipe, rear-end, rear-rear, and head-on crashes. The General Estimates System (GES), which is a collection of police reported crash samples from the United States and is the data source for this thesis, also adopts this classification. Further details on this dataset are provided in Chapter 3.

Singular crashes refer to crashes not involving other moving objects, e.g., running off road and colliding with a fixed object on the road. Angular crashes refer to those crashes with two vehicles moving in different but not completely opposing directions. There is a striking vehicle and a struck vehicle in these crashes. Similarly, rear-end crashes also have a striking vehicle and a struck vehicle. In the pre-crash moments, the striking vehicle follows the struck vehicle, typically in the same lane. Sideswipe refers to crashes that involve two vehicles moving parallel in the same direction. Crash occurs because one of the vehicles deviates from its lane. Rear-rear refers to two vehicles crashing tail-to-tail; and head-on refers to two vehicles crashing head-to-head. Due to the relatively small number of rear-rear, head-on, and sideswipe crashes (less than 20% in GES), this thesis focuses on singular, angular, and rear-end crashes.

Given that crash injury severities and crash types are closely associated (Farmer, et al., 1997; Kockelman & Kweon, 2002), it is possible that variables affecting injury severity also affect crash types. Previous studies on crash types investigated environmental conditions, crash locations, driver behaviours, and driver characteristics (Ghazizadeh & Boyle, 2009; Neyens & Boyle, 2007; Ryan, Legge, & Rosman, 1998). These studies showed that variables such as road surface conditions, road type, time of day, and driver age are in fact significantly associated with crash types. Ryan et al. (1998) was based on descriptive statistics, whereas Neyens and Boyle (2008) and Ghazizadeh and Boyle (2009) utilized inferential statistics.

Ryan et al. (1998) revealed age differences in crash types. They found that young drivers were involved relatively more in singular crashes, mid-age drivers in rear-end crashes, and old drivers in angular crashes. However, given that Ryan et al. (1998) was based on descriptive statistics, other variables, such as road type and weather, were not controlled for.

Similar to this thesis, Neyens and Boyle (2008) and Ghazizadeh and Boyle (2009) utilized statistical modelling techniques and focused on three most common crash types: singular, angular, and rear-end. In general, angular and rear-end crashes make up a larger portion of crashes in urban settings than they do in rural settings; similarly singular crashes comprise a larger portion of crashes that occur at night than they do for crashes that occur in daylight (Ghazizadeh & Boyle, 2009; Neyens & Boyle, 2007). Moreover, the proportion of singular crashes on bad road surfaces is larger than that on dry road surfaces (Neyens & Boyle, 2007). A similar effect is observed for alcohol vs. non-alcohol use and speeding vs. non-speeding. In addition, female drivers are more likely to be involved in singular and angular crash than male drivers; whereas male drivers are more likely to be involved in rear-end crashes than females (Ghazizadeh & Boyle, 2009).

To the author's knowledge, Neyens and Boyle (2008) and Ghazizadeh and Boyle (2009) are the only studies which considered the associations between driver distraction and crash type, and their results seem to be inconsistent. Specifically, Ghazizadeh and Boyle (2009) found that drivers were less likely to be involved in rear-end crashes compared to angular crashes when distracted by passengers, and compared to singular crashes when distracted by in-vehicle electronic devices; whereas Neyens and Boyle (2007) found these contrasts to be insignificant for teenage drivers. These discrepancies might be in part due to different driver populations studied: the former used data from Missouri and looked at all driver ages, whereas the latter used GES and looked at teenagers. This thesis aims to build a more comprehensive model, which utilizes data from all ages and at a national level, and considers age – distraction interaction. Moreover, as stated previously, drowsiness/fatigue will also be included among distraction types studied. Drowsiness/fatigue is often analyzed separately from distractions and previous research suggests that the majority of drowsy-driving crashes are singular run-off the road crashes (Pack et al., 1995).

Chapter 2
Effects of Distractions and Driver's Age on Driving Performance and Behaviour

Distractions and age are expected to ultimately influence crash outcomes by first influencing driving performance (e.g., brake reaction times) and behaviour (e.g., lane changing behaviours). Thus, understanding their effects on driving performance and behaviour can provide useful insights into the results of this thesis. The following review mainly focuses on experimental research in controlled settings, which lay the foundation for the discussion of statistical results obtained in this thesis on observational data. At times, the author has generated expectations regarding the results of this thesis, in particular trying to tie crash outcomes to performance and behaviour changes observed in controlled settings. However, due to two particular reasons, generating hypothesis regarding the associations between different distraction types and crash outcomes proved to be an impossible quest. There is minimal research explicitly comparing the effects of different distraction types on driving performance and behaviour. Moreover, task demand levels in experimental settings are generally decided and controlled by the researchers and might be significantly different than the likely self-paced task demands experienced by the drivers on the road.

2.1 Effects of Distractions

There have been numerous controlled studies documenting the effects of engaging in distracting tasks while driving (for a review see Regan, Lee, & Young (2008)). In general, these studies revealed that distracted drivers have slower responses to and a higher likelihood of missing critical traffic events such as braking lead vehicles, pedestrian intrusions, and changing traffic lights. Distractions also interfere with lane keeping abilities: increasing lane deviations.

Distractions also lead to a change in driver behaviour decreasing the frequency of lane changes and driving speeds, and increasing following distances. These changes indicate risk compensations; although it is unclear if the drivers intentionally choose to compensate for the effects of distractions or if there is a cognitive/perceptual saturation which lead to an unconscious change in behaviour.

Although a majority of drivers self-report to compensating for the negative effects of distractions (Baker & Spina, 2007) (24% for passenger related, 80% for hand-held cell phone, and 46% for in-vehicle distractions), a simulator study by Horrey et al. (2008) showed that there are no significant relations between participant’s estimates of distraction effects and their actual performance decrements, lending support to the notion that drivers may not be well-calibrated to the effects of distractions. Regardless of the underlying reason, compensatory behaviours are expected to have a significant impact on the crash outcomes.

2.1.1 Cell Phone and Passenger Related Distractions

A simulator experiment with 20 subjects revealed that lane deviations were significantly more likely to occur when subjects were conversing on a cell phone; there were no differences observed between hand-held and hands-free phones (Abdel-Aty, 2003). In another driving simulator study, 48 subjects were asked to detect signals flashing at the edge of the simulator screen (Strayer & Johnston, 2001). When they were conversing on a cell phone, the probability of missing the signal doubled. In addition, a field experiment with 12 subjects showed a decreased frequency of mirror glances and an increased heart rate during a cell phone conversation task, indicating a heavier information processing workload (Brookhuis, de Vries, & de Waard, 1991).

Lesch and Hancock (2004) examined the effects of cell-phone conversations in a simulator experiment with 36 subjects. Brake reactions were slowed by 0.18 s, but stopping times were reduced by 0.34 s, indicating that distracted drivers pressed the brake pedal harder. Although these participants braked harder, they still ended up about 50% closer to intersections, and stop light compliance fell by 14%. These results indicate that even though distracted drivers tried to compensate for the delay in their initial responses by braking harder, the compensation was simply not enough.

Given that conversing on the phone and with a passenger constitute similar tasks, several studies explicitly compared these two types of distractions. In a driving simulator experiment where subjects had both complex and simple conversations, cell phone and passenger conversations were found to equally increase mental workload (measured through pupil dilation) and equally degrade visual search behaviour (Nunes & Recarte, 2002). Similarly, another driving simulator study found that talking with a passenger and talking on a cell phone both marginally increased response time to a pedestrian incursion event by the same extent (Laberge, Scialfa, White, & Caird, 2004). Meanwhile, participants appeared to compensate for these performance decrements by slowing down during both distracting tasks.

Drews et al. (2008) conducted a simulator experiment, where subjects conversed on daily-life topics with an experimenter acting as a passenger or talked on the cell phone with a real-life friend about a life-threatening past experience. These subjects also performed a navigation task in an urban setting, and were observed to commit more errors while conversing on the cell phone. Two details in this experiment need special attention. The content of the cell phone conversations were likely more cognitively demanding than daily-life topics. Further, even though the authors claimed that the passengers mitigated their negative effects by pointing out traffic demands, another simulator study found that real-life friends who are passengers do not change the way they interact with drivers when traffic turns heavy (Laberge, et al., 2004).

Overall, talking with passengers appears to have similar effects as talking on a cell phone. Moreover, talking on a cell phone appears to increase mental workload, interfere with effective visual scanning and detection, and diminish lateral and longitudinal control. Although the studies mentioned previously suggest that drivers slow down when talking on a cell phone, there has also been literature suggesting the opposite effect. In particular, Horberry et al. (2006) found that their participants maintained faster speeds when conversing on a cell phone compared to when they were not. This inconsistent result might be due to several factors, one of which is the different conversation content. The participants in Horberry et al. (2006) answered binary choice questions (i.e., participants answered a series of general knowledge questions presented by the experimenter over the simulator’s audio system. The questions were followed by two alternative answers and participants had to choose the correct answer), whereas the participants in Nunes and Recarte (2002) and Laberge et al. (2004) had conversations involving story telling.

Manipulating cell phones, i.e., dialling or texting, also have significant negative effects on driving performance. Dialling a cell phone impairs a driver’s ability to maintain consistent speed and lateral position on the road (Green, Hoekstra, & Williams, 1993; Lesch & Hancock, 2004; Reed & Green, 1999). For instance, Brookhuis, et al. (1991) observed that when their subjects manually dialled numbers, the steering wheel handling stability decreased.

Text messaging while driving is likely riskier than simply talking on a cell phone, and has been shown to interfere with longitudinal and lateral control of the vehicle (Hosking, Young, & Regan, 2009). In a 20-subject simulator experiment, Hosking et al. (2009) found that drivers' ability to maintain their lateral position on the road and to detect and respond appropriately to traffic signs was significantly reduced when they were text messaging. In addition, the authors observed that drivers spent up to 400% more time with their eyes off the road when texting. The authors did not find any changes in the average speeds adopted by the participants. To sum up, manipulating cell phones not only significantly interferes with drivers' normal visual scanning patterns; it also impairs lateral and longitudinal control. However, there is no evidence suggesting that drivers slow down when texting.

Given that conversing on the phone and with a passenger are similar cognitive tasks, it is expected that they would have similar effects on crash outcomes; however, drivers' compensation behaviours may be different for these two distraction types. Although the literature is not consistent with regards to this issue, there is some evidence suggesting that more drivers report that they feel the need to slow down or maintain larger following distances when they are talking on their cell phones compared to when they are distracted by passengers (Baker & Spina, 2007). In addition, a simulator study revealed that subjects maintain greater following distances when they are talking on a cell phone than they do when conversing with a passenger (Amado & Ulupinar, 2005). On the other hand, manipulating a cell phone (e.g., dialling or texting) is a fundamentally different task than conversing on a cell phone. Although no previous research has explicitly compared the two, it has been suggested that manipulating a cell phone is likely riskier than conversing on one (Hosking, et al., 2009). Given that manipulating a cell phone results in visual and manual distraction and that driving is a highly visual task and also given that there is no evidence suggesting a reduction in speed when manipulating cell phones, it is expected that more serious injuries would occur when drivers are dialling or texting on a cell phone compared to when they are conversing on one. It should be noted that the level of task demand in these controlled studies were set by the experimenters and might be significantly different than the likely self-paced task demands experienced by the drivers on the road. Thus, the confidence in such an expectation should be low.

2.1.2 Other Types of Distraction: In-vehicle, External, Inattention, and Drowsiness

Although cell phones and passenger related distractions have attracted major attention from the research community, other types of distractions have also been raised as concerns, in particular as more in-vehicle entertainment technologies are introduced in the vehicle. These other distraction types include in-vehicle (e.g., eating, manipulating controls) and external (e.g., roadside advertisements) distractions, as well as inattention (e.g., being lost in thought).

Horberry et al. (2006) conducted a simulator experiment with 31 subjects comparing the effects of in-vehicle entertainment systems and cell phones. They found that subjects increased their speeds during cell phone conversations, but decreased their speeds during in-vehicle entertainment tasks (a series of car radio and cassette player manipulations). Both tasks degraded reactions to an unexpected hazard (i.e., a pedestrian suddenly crossing the road in front of the vehicle).

Whilst eating or drinking does not seem to significantly influence driving performance per se, drivers' mental workload appears to increase during these activities (Young, Mahfoud, Walker, Jenkins, & Stanton, 2008). Young et al. (2008) speculate that the driving performance may not diminish while eating/drinking because drivers can adapt to circumstances to a certain extent. However, such adaptation may break down during abnormal situations, and comes at a cost of increased workload, potentially leading to an increase in crash risks. Because in-vehicle distractions, including adjusting on-board systems and eating/drinking, require similar kinds of attentional resources (a hand off the wheel and eyes off the road) as dialling/texting on a cell phone, it is expected that they would have similar kinds of effects on crash outcomes but potentially with different magnitudes.

External distractions also have significant effects on driving performance. Young and Mahfoud (2007) assessed the effects of roadside billboards in a simulator experiment with 48 subjects. They found that drivers who were distracted by external advertisement boards deviated from their lanes more frequently and had larger variations in following distances. Distracted drivers also had an increased mental workload as measured through the recall of street signs (a secondary task workload measure). The authors found that in some occasions, distracted drivers' visual attention was drawn away from more relevant road signage, suggesting a decreased likelihood of detecting emerging critical events. Drivers who are distracted by external objects look outside of the vehicle and can still pick up roadway information on their periphery as opposed to drivers who are distracted by in-vehicle sources. Thus, crashes resulting from external distractions may not be as severe.

Driver's attention might also diminish in the absence of non-driving-related activities, e.g., being lost in thought (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006). Some studies, including this thesis, treat inattention in the absence of non-driving-related activities as a distraction category (Ranney, Mazzae, Garrott, & Goodman, 2001), whereas others distinguish inattention from distraction (Beirness, 2002). Regardless of categorization, inattention in the absence of non-driving-related activities is a potential problem for traffic safety and needs to be studied.

It should be noted that mental tasks utilized in a controlled experiment are different from what people normally do, e.g., daydreaming and being lost in thought. Due to the difficulty of manipulating such implicit activities, experiments on this topic are rare. Given that inattention (i.e., lost in thought and looked but did not see) does not demand visual or manual resources, which are highly important in driving, and given that drivers still adopt less risky behaviours when performing cognitively demanding tasks, it is expected that this distraction type would not affect crash outcomes as much as previously discussed ones.

A few studies evaluated the effects of cognitive tasks on driving performance. Recarte and Nunes (2003) conducted an experiment with 12 subjects driving an instrumented vehicle in real traffic. Mental tasks were introduced to subjects in the form of verbal learning (summarizing a long verbal speech) and verbal reproduction (reproducing a short verbal statement). Their results suggest that these mental tasks induced spatial gaze concentration as well as visual-detection impairment (late detection and poor identification). Lavalliere et al. (2011) monitored 106 drivers in an instrumented vehicle under varying levels of cognitive demand by utilizing a number recall task. Regardless of demand level, cognitive workload reduced the likelihood of lane changes and resulted in slower speeds. Thus, purely cognitive distraction can lead to a less effective visual scanning behaviour. However, drivers also appear to compensate for such degradation by reducing the driving demands.

As mentioned previously, drowsiness can lead to a withdrawal of attention from the roadway and is included in this thesis as a type of distraction. The effects of drowsiness on accidents has been investigated widely (for a review see Dinges (1995)). Drowsiness/fatigue is, in general, associated with slower reaction times and a deficit in information processing. In the driving context, Ingre et al. (2006) examined the performance of drowsy drivers in two simulator sessions: after a normal night sleep and after working a night shift. Before each session, the subjects also evaluated themselves on a sleepiness scale. Results showed that a high sleepiness rating is positively correlated with increases in lateral deviations and eye blink durations. As reported previously, the majority of drowsy-driving crashes are singular crashes off-the road (Pack, et al., 1995). Based on these findings, it is expected that drowsy drivers would be more likely to be involved in singular crashes, which are run-off-road crashes (also referred to as lane departure accidents). However, it is not clear as to how drowsiness effects would compare to the effects of other distraction types.

2.2 Age Differences

In general, older drivers maintain lower speeds and larger following distances than younger drivers (Boyce & Geller, 2002), exhibit fewer lane changes than mid-age drivers, and travel in the left most lane less often than both young and mid-age drivers (Lavalliere, et al., 2011). However, the U-shaped crash risk function suggests that older drivers differ from younger and mid-age drivers more than just in conservativeness in behaviour. Working memory, vision, judgment, and how they cope with distracting activities all have profound implications for different age groups in terms of their exhibited driving behaviour and performance, and thus the outcomes of their crashes.

2.2.1 Working Memory

Since distraction taxes drivers' working memory, it is necessary to understand how working memory limits differ across age groups. In a driving simulator experiment, the effects of a visual/verbal memory task were examined (Bao, Kiss, & Wittmann, 2002). Older participants (ages 60 to 80) and younger participants (ages 20 to 31) performed one of three tasks: a memory task (in which German words were presented visually in various colour, shape, size, and location), a driving task (in which participants were instructed to stay in the right lane and brake upon seeing a red light), or a dual task (in which both the memory and driving tasks were performed at the same time). Older participants remembered fewer words on the memory task than younger participants. The memory task prolonged older participants' reaction times to the red light and increased their number of lane deviations, while younger participants were unaffected.

de Ridder et al. (2002) examined spatial memory via two experiments with the same experimental design: one conducted in a simulator, the other one on the road. In these experiments, older (average age: 71.3) and younger (average age: 27.4) subjects drove a set route through a neighbourhood, while the experimenter pointed out particular landmarks to be remembered by the subject. After the first session, subjects were instructed to drive to various locations in the neighbourhood and to point out these landmarks. Older subjects had larger errors in recalling the intersections and the landmarks than younger subjects. The trends observed in the simulator was the same as the ones observed on the road, generalizing the validity of findings obtained through a virtual driving task where the experimenters had more control over extraneous variables. In general, older drivers have low working memory capacity than younger drivers, and thus may be influenced more by distractions than younger drivers.

2.2.2 Vision

As humans age, their visual capabilities, such as visual detection, get impaired. Being able to detect and identify objects in the periphery of the visual field during a complex driving task is important to anticipating impending hazards (e.g., pedestrian detection). In a driving simulator study, Chaparro and Alton (2000) observed older (ages 64 to 85) and younger subjects (ages 18 to 41) as they drove in either a heavy or light traffic condition. In general, older subjects drove slower, had more accidents, and correctly identified fewer letters in a simultaneous peripheral letter task. The older subjects' higher accident and lower correct letter identification rates were amplified by the increase in traffic complexity. The authors pointed out that the results may have been influenced by the fact that older subjects may have had more difficulty adapting to the driving simulator.

Apart from the differences in peripheral vision, the visual sampling methods are also different between novice drivers (who are generally younger) and experienced drivers (who are generally mid-age or older). Novice drivers concentrate their search in a smaller area, close to the front of the vehicle when compared to more experienced drivers (Mourant & Rockwell, 1972).

2.2.3 Collision Judgment

DeLucia et al. (2003) examined age differences in collision judgment. The authors conducted three experiments with younger (ages 18 to 29) and older subjects (ages 50 to 76). In the first experiment, participants observed a rectangular object that moved toward a pole from both moving and stationary viewpoints. The results showed that older subjects made more conservative judgments about when the objects would collide, i.e., anticipated shorter time to collisions (TTCs). In the second experiment, participants observed two cubes, either on course to collide or not to collide from both moving and stationary viewpoints. The result was that the younger subjects made more accurate judgments on whether there would be a crash, and more accurate judgments on the TTC when there was a crash. In the third experiment, where displays were more egocentric, square objects approached the observer, who had both moving and stationary viewpoints. The older participants again had shorter TTC judgments than younger participants. Thus, older drivers appear to have higher thresholds for TTC acceptance than younger drivers. For example, when stopped at an intersection, an older driver may accept a 10-second gap and proceed to join the traffic, but reject a 6-second gap and wait at the stop sign; while a younger driver may accept the 6-second gap.

2.2.4 Coping with Distractions

In a driving simulator study, older (aged 65 to 74) and younger subjects (aged 18 to 25) performed a simple driving task in which they followed a lead vehicle, and a distracted driving task in which they conversed with the experimenter by using a hands-free cell phone (Strayer & Drews, 2004). Overall, older subjects drove slower and with greater following distances than younger subjects. Although both younger and older subjects were affected by the cell-phone task, as suggested by the delay in braking onset and the increase in following distances, the brake reaction times of younger subjects when distracted were equivalent to that of older subjects when not distracted. Thus, conversing on a cell phone degraded the reaction times of young subjects to the level of older subjects who were not engaged in a phone conversation.

Lavalliere et al. (2011) monitored 106 drivers from three age groups (20-29, 40-49, and 60-69) in an instrumented vehicle under varying levels of cognitive demand. The results showed that the 40’s age group had a 115% higher likelihood of exhibiting lane changes than the 60’s group. In addition, drivers in their 20’s and 40’s travelled more often in the leftmost lane compared to drivers in their 60’s. These results suggest that older adults adopt a more conservative driving style by not traveling in the leftmost lane as much as the younger groups and being less likely to change lanes than drivers in their 40’s. Regardless of demand level, cognitive workload reduced the likelihood of lane changes for all age groups. This suggests a tendency in drivers of all ages to regulate their behaviour in a risk reducing direction in response to added cognitive demand.

The results of these two experiments indicate no evidence that older subjects were coping with distractions better than younger subjects. Nor did they support that younger subjects were less affected by distracting tasks. Further controlled and naturalistic studies examining age-distraction interactions are needed.

2.3 Gaps in the Literature and Thesis Objectives

Crash injury severity has been widely studied. For example, Kockelman and Kweon (2002) adopted an ordered probit model and Xie (2009) utilized a Bayesian ordered probit model to predict injury severity for various factors, such as driver's age, gender, alcohol use, and vehicle type. However, the associations between driver distraction and injury severity have not been widely studied. To our knowledge, only two injury severity studies have focused on different types of driver distraction, but they were limited to police and teenage drivers respectively (Liu & Donmez, 2011; Neyens & Boyle, 2008). Thus, further research is needed to assess the effects of different distraction types on injury severity given various driver demographics.

Study One in the following section extends the scope of previous studies by considering drivers of all age groups rather than just young drivers. With the proliferation of technology and in-vehicle devices used by drivers of all ages, this study tries to investigate the influence of age-distraction interaction on crash injury severities. Investigation is carried out by employing an ordered logit model to predict how driver distraction and age influence the odds that an occupant will sustain a severe injury. As an initial step to addressing this research gap, Study One focuses on two-vehicle crashes only.

Another important aspect of the increased risks for distracted drivers is how such risks translate into the frequency of different crash types. The three most common types of crashes are: angular crash with another vehicle, rear-end crash, and crash with a fixed object (Ghazizadeh & Boyle, 2009). Rear-end crashes usually occur when vehicles are traveling in the same direction and can be attributed to very short headways and failure to brake appropriately. Angular crashes usually involve colliding with vehicles not travelling in the same direction and can be attributed to improper lane changing decisions and lane keeping (Neyens & Boyle, 2007). Crashes with fixed objects are typically due to failures to observe fixed objects on the road or to maintain lateral position. These differences are important when considering what factors are likely to be involved in crashes and how crash risks associated with these crash types can be mitigated.

To the author's knowledge, Neyens and Boyle (2008) and Ghazizadeh and Boyle (2009) are the only studies which considered the associations between driver distraction and crash type. However, neither of these studies investigated how age enters in to the picture. The goal of Study Two, presented in Chapter 4, is to provide insights into how distractions and driver's age influence the odds that a driver will be involved in a particular type of crash. A multinomial logit model is built to address this research objective. The focus is on vehicles that were in a singular crash, vehicles that struck a lead vehicle from the rear, and vehicles that struck another vehicle or were struck in an angular crash.

Finally, although drowsiness/fatigue has been studied widely, it has not been compared to other distraction types explicitly. Both Study One and Study Two consider drowsiness/fatigue as a distraction type given that it results in progressive withdrawal of attention from the roadway (Williamson, 2009).

Chapter 3
Study One: Effects of Distractions and Driver's Age on Injury Severities

By employing an ordered logit model, this study aims to estimate whether driver distraction, drivers' age, or their interaction have significant effects on crash injury severities. The dependent variable utilized is the injury severity of occupants involved in a crash, including the drivers and their passengers. In addition to the main and interaction terms of distraction type and driver age, the model statistically controls for other factors such as environmental and crash-specific factors. An ordered logit model is an extension of the binary logistic model, but has the capability of treating multi-level categorical response variables that have an inherent order. Like the logistic model, both numerical and categorical explanatory variables can be included.

3.1 Data Description

As mentioned in Chapter One, data from the General Estimates System (GES) from the year 2003 to the year 2008 were used in this model, because GES has the best driver distraction information for the longest period of time at a national level (U.S.). Although distracted driving constitutes a small fraction of the sample population, the mere size of the dataset (202,808 crash occupant records) made it possible to draw inferences on crashes with distracted drivers. A general limitation with the use of crash databases is that these data are based on police reports and may present a biased sample (Muelleman, et al., 2007). For example, driver distraction might be underreported, especially if there are fatalities. Further, it is also possible that drivers may not be honest in reporting their distracting activities due to social acceptability (e.g., not reporting that they were distracted or stating that they were lost in thought when they were actually texting on a cell phone). In the 100-car naturalistic study, Dingus et al. (2006) observed that 80% of crashes and 65% of near-crashes involved driver distraction, while in GES, only 21% of drivers were reported to be involved in distracting activities. However, it should be noted that the majority of the 69 crashes observed were low-g-force physical contact or tire strikes, which did not cause property damage, hence are not police-reported crashes. Thus, the 100-car naturalistic study only had a very small number of crashes (a total of 12 were reported) that are representative of police-reported crashes. Still, the underreporting issue had been acknowledged previously, and several states are making efforts to collect better data on driver distraction (Sundeen, Accessed July 31, 2010); however, it is a drawback for all studies based on police-reported data.

The GES dataset is a stratified weighted sample of crashes, representing national crash trends, and includes information on several aspects of a crash such as driver and passenger demographics, crash types, types of distractions, and injury severities. GES classifies injury severity by an ordinal scale with levels of no or possible injuries, non-incapacitating, incapacitating, and fatal injuries. The crash data were collected retrospectively; therefore exposure information (e.g., the amount of time spent performing distracting activities and how much people drive) is unavailable. As a result, the current study cannot assess crash risk. This study rather focuses on the crash outcome, in particular the injury severities, given that a crash has already occurred. GES identifies the driver that is distracted, however it does not provide information on which driver is at fault or the root cause of a crash. Thus, the results of this study should also not be viewed as claiming causation.

This thesis aims to assess associations between age-distraction interaction and crash injury severities. As a first step in understanding these associations, this thesis focuses on two-vehicle crashes, for which the first harmful event is the direct crash of two moving vehicles. There are two reasons for focusing on this specific type of crashes. First, the number of potential factors affecting such crashes is limited compared to crashes which involve third party vehicles, persons, or objects. Thus, modelling is relatively easier. Second, the victims of two-vehicle crashes represent the largest proportion of all crash victims (approximately 80%) according to GES data from 2003 to 2008. It is reasonable to consider the vast majority before going into details for other crash types.

3.2 Distraction Type Classification

The following distraction types are reported in GES and have been included in the analysis. These levels were coded in GES as mutually exclusive, that is, a driver was not reported to belong in more than one level.

- In-vehicle distraction (in-vehicle physical activities such as eating, drinking, and using entertainment and A/C systems)
- Passenger related distraction
- Talking on a cell phone
- Dialling/texting on a cell phone
- External distraction (paying attention to non-driving related objects outside of the vehicle, e.g., commercial boards, natural scene, or people off the road)
- Inattention ("looked but did not see" and "being lost in thought")
- Drowsiness
- No distraction

In order to detangle the effects of different distraction types, crashes where both drivers were identified to be distracted were excluded from analysis. For example, if one driver is inattentive and the other one is distracted by an in-vehicle source, then it is impossible to separate the effects of inattention and in-vehicle distractions on the injury severities observed in this particular crash.

3.3 Model Covariates

The model was built using an observation for each occupant (either driver or passenger) involved in the crash. The response variable is the injury severity for that occupant. The observation for each occupant was also accompanied by information on both of the drivers involved in the crash, such as age, and gender. Thus, the characteristics of both drivers were used as covariates for all occupants. Other covariates included in the model account for the environmental conditions, crash profile, and occupant information.

Poor lighting conditions have been shown to increase crash risk (Massie, et al., 1995). Lighting was therefore included as a variable with two categories: daylight vs. non daylight. Previous research revealed that crash location influences injury severity (Muelleman, et al., 2007). Thus, urban/rural and highway/non-highway roads were included in the model. Road alignment (curvy vs. straight) and relation to junctions (intersection vs. non intersection) were also included. Given that weather and road surface conditions are closely related, only weather (good vs. bad) was included in the model.

Three variables describing the crash profile were used: alcohol use, speeding, and crash types. These three variables were previously shown to influence injury severity (Kockelman & Kweon, 2002; Neyens & Boyle, 2008). In the dataset, angular (36%) and rear-end (42%) crashes constitute the majority of two-vehicle direct crashes, and the rest of the four types (sideswipe passing, sideswipe meeting, backed-into, and head-on) constitute less than 22%. Thus, in the model, three types of crashes were included: angular, rear-end, and other.

There are discrepancies across how researchers classify different age groups. Common age thresholds used in driving safety and injury assessment are 25 and 65 (Margolis et al., 2002; McGwin, Sims, Pulley, & Roseman, 2000). Thus, this thesis adopts these thresholds for categorizing both drivers' and passengers' age. Occupants' (i.e., drivers and passengers) age was defined to have three levels: less than 24 years old, 25 to 64 years old and 65 years old and up. The gender and the seating position (front or back) of the occupant were also included in the model. Seatbelt use was another variable used in the model; it has been shown to be a significant factor in injury severity (Kockelman & Kweon, 2002).

The majority of previous injury severity studies account for the characteristics of only the driver of the vehicle which the occupant belongs to (Kockelman & Kweon, 2002; Neyens & Boyle, 2008). Given that the at-fault driver is not identified in GES, it is important to account for the characteristics of the other vehicle's driver as well. Thus, driver demographics were incorporated in the model as combinations of the two drivers' profiles. Drivers' gender has three levels: one male and one female, both male, or both female drivers. As discussed above, the age groupings for drivers were based on commonly used thresholds: young (16 to 24), mid-age (25 to 64), and old (65 and up). Thus, drivers' age had six levels: both young, one young and one mid-age, one young and one old, both mid-age, one mid-age and one old, and both old.

3.4 Descriptive Statistics

A weighted total of 23,525,830 occupants (202,808 un-weighted), including 17,196,621 drivers (148,246 un-weighted), were included in the model. 19.7% of the drivers were reported to be either distracted or drowsy. Moreover, the proportion of crashes involving different distractions varied across age groups.

Table 1: Injury severity data: weighted frequencies of drivers that were involved in a crash (percentage in row total) by driver age and distraction type

Type of distraction	Driver’s age			Row total
	Young	Mid-age	Old	
Inattention	843,765 (32.6%)*	1,450,602 (56.1%)	289,921 (11.2%)	2,584,288
In-vehicle sources	72,842 (39.8%)	103,770 (56.7%)	6,347 (3.47%)	182,959
Passenger related distraction	30,168 (36.3%)	51,497 (61.9%)	1,540 (1.85%)	83,206
Dialling/texting on cell phone	17,882 (46.2%)	20,738 (53.5%)	122 (0.31%)	38,743
Talking on cell phone	25,779 (44.1%)	30,041 (51.4%)	2,662 (4.55%)	58,482
External distraction	111,628 (38.3%)	158,174 (54.2%)	21,957 (7.53%)	291,759
Drowsiness	31,584 (36.9%)	48,933 (57.2%)	4,990 (5.84%)	85,507
No distraction	4,059,446 (30.0%)	8,185,817 (60.4%)	1,266,416 (9.35%)	13,551,679
All drivers (column total)	5,193,094 (30.8%)	10,409,572 (59.7%)	1,593,955 (9.50%)	17,196,621

* Percentage in row total

Table 1 is based on the weighted count of drivers in the dataset. It presents each age group’s proportion in the entire driver sample (last row percentages) and each age group’s proportion within a particular distraction type (cell percentages excluding the last row). Mid-age drivers represent the largest proportion at 59.7%, followed by young drivers at 30.8%, and finally old drivers at 9.5%.

Young drivers represent a larger portion among distracted drivers (32.6% - 46.2%), then they do among non-distracted drivers (30%). Their portions peak for cell-phone related distractions (dialling/texting on the cell phone: 46.2%; talking on the cell phone: 44.1%). Compared to their proportion in non-distracted drivers (60.4%), mid-age drivers’ proportion in all distraction categories but the passenger-related category (61.9%) is lower. As for older drivers, their proportion in all distraction categories except inattention (11.2%) is lower than their proportion among non-distracted drivers (9.35%).

3.5 Ordered Logit Model

An ordered logit model was built using the GENMOD procedure in SAS (Statistical Analysis System) version 9.2. Based on the GES data, injury severity is classified on an ordinal scale with levels of no or possible injuries, non-incapacitating, incapacitating, and fatal injuries. This model predicts the odds of severe injuries given that a crash has occurred. Therefore, the results should not be interpreted as crash risk or the odds of being involved in a crash with a certain level of injury severity. Odds of a severe injury are defined as the probability of a more severe injury divided by the probability of a less severe injury. A higher value of odds indicates a higher likelihood of a more severe injury (same as moving up on the ordinal scale). Moreover, if the value of odds is larger than one, then the probability of observing a more severe injury is greater than 50%.

An ordered logit model provides a strategy that takes into account the ordinal nature of data (Stokes, Davis, & Koch, 2000) and is represented with a set of equations as:

$$\ln\left[\frac{p_1}{1-p_1}\right] = \beta_{01} + \mathbf{\beta X} \qquad (1)$$

$$\ln\left[\frac{p_1 + p_2}{1-p_1-p_2}\right] = \beta_{02} + \mathbf{\beta X} \qquad (2)$$

$$\ln\left[\frac{p_1 + p_2 + p_3}{1-p_1-p_2-p_3}\right] = \beta_{03} + \mathbf{\beta X} \qquad (3)$$

where p_1 represents the probability of a fatal injury, p_2 represents an incapacitating injury, and p_3 represents a non-incapacitating injury. Thus, the equations represent the log-odds of severe injuries for: "fatal" versus "incapacitating", "non-incapacitating", and "no injuries" (eqn. 1); "fatal" and "incapacitating" versus "non-incapacitating" and "no injuries" (eqn. 2); "fatal", "incapacitating", and "non-incapacitating" versus "no injuries" (eqn. 3). β_{0i} represents the intercept and $\boldsymbol{\beta}$ is the matrix of coefficient estimates for predictor variables, $\mathbf{X}$.

A general issue with statistical models built on crash data is the incorrect assumption of independent observations. In theory, there are dependencies in crash data, as there can be multiple injuries within a vehicle and multiple vehicles involved in a crash. An ordered logit model is theoretically not appropriate for dependent data. However, in practice, logit models give approximate results that are very close to theoretically correct models such as general estimating equations (GEE) and multilevel logistic models, which themselves face many assumption issues when applied to crash data (Lenguerrand, Martin, & Laumon, 2006). Thus, this thesis used an ordered logit model with the assumption of independence.

Specific contrasts of interest were setup using the "estimate" statement in SAS, which provided odds ratios. The odds ratio is the ratio of odds of an event (e.g., a more severe injury) occurring in one group (e.g., inattentive drivers) to the odds of it occurring in another group (e.g., non-distracted drivers). An odds ratio greater than 1 indicates that the group in the numerator has higher odds than the group in the denominator.

3.6 Model Results

Tables 2, 3, and Figure 1 present the results obtained through contrasts of interest. The results are reported in terms of increasing injury severity, that is, the greater the estimated contrast coefficient and corresponding odds ratio, the higher the likelihood of a more severe injury. Given the large sample size, a confidence level of 99.9% (or α = .001) was adopted for determining statistical significance.

Table 2: Injury severity results for model covariates (excluding distraction and driver age, which are reported in Table 3)

Comparisons	Estimate*	Odds Ratio (OR)	95% Confidence Interval (CI)
Environmental conditions			
Non daylight vs. daylight	0.14	1.16	1.15 – 1.16
Rural vs. urban	0.25	1.29	1.29 – 1.29
Curvy vs. straight road	0.17	1.18	1.18 – 1.19
Bad vs. good weather	-0.12	0.88	0.88 – 0.89
Highway vs. non highway	-0.06	0.94	0.94 – 0.95
Intersection vs. non intersection	-0.09	0.91	0.91 – 0.92
Crash profile			
Alcohol vs. no alcohol	0.81	2.24	2.23 – 2.26
Speeding vs. no speeding	0.19	1.20	1.20 – 1.21
Angular vs. rear-end crash	0.55	1.74	1.73 – 1.74
Occupants (drivers and passengers)			
Female vs. male	0.58	1.79	1.79 – 1.80
Seatbelt vs. no seatbelt	-0.61	0.54	0.54 – 0.54
Front seat vs. back seat	0.22	1.24	1.24 – 1.25
Young vs. mid-age	-0.31	0.73	0.73 – 0.73
Old vs. mid-age	0.03	1.03	1.03 – 1.04
Drivers' gender (baseline: both male)			
Female & male	-0.13	0.88	0.88 – 0.89
Both female	-0.23	0.80	0.80 – 0.80

* All estimates are significant at $p<.0001$

The estimates reported in Table 2 show that in general, among environmental factors, crashes in non-daylight conditions (OR=1.16), rural roads (OR=1.29), and curvy roads (OR=1.18) had higher odds of resulting in more severe injuries. In contrast, adverse weather (OR=0.88) and highway driving (OR=0.94) resulted in decreased odds. These findings were in accordance with (Neyens & Boyle, 2008), which focused only on teenage drivers. Crashes on intersections had a lower likelihood of resulting in more severe injuries than crashes on non-intersections (OR=0.91). When a crash involved alcohol (OR=2.24) or speeding (OR=1.20), likelihood of more severe injuries increased. Angular crashes were more likely to result in more severe injuries than rear-end crashes (OR=1.74). This effect was in line with (Kockelman & Kweon, 2002) and might be due to the potentially higher relative speeds in angular crashes and fewer side-protection systems in vehicles.

As expected, occupants' injury severities were significantly associated with occupants' age, gender, seating position, and seatbelt use (Kockelman & Kweon, 2002). Female occupants were more likely to sustain more severe injuries than male occupants (OR=1.79). Using a seatbelt decreased the odds of more severe injuries (OR=0.54), whereas sitting in the front increased the odds (1.24). Compared to the baseline of two male drivers, a female and a male (OR=0.88) drivers' crash and two female drivers' crash (OR=0.80) were likely to result in decreased injury severities.

As reported in Table 3, comparisons were drawn in three separate age groups with distracted drivers versus non-distracted drivers in the same age group. Thus, effects of distractions for different age groups were analysed. For young drivers, dialling or texting on cell phone (OR=1.94) yields the highest likelihood of severe injuries observed in a crash. Other distractions such as in-vehicle sources (OR=1.22) and passengers (OR=1.10) have lower odds but still result in a higher likelihood of more severe injuries compared to no distraction. On the other hand, inattention (OR=0.91), talking on the cell phone (OR=0.91), and external distractions (OR=0.51) decrease the likelihood of severe injuries compared to no distraction. Last but not least, crashes involving drowsy (OR=1.58) young drivers are more likely to result in severe injuries than those involving non-distracted young drivers. Thus, for young drivers, there is a 50% increase in odds. Interestingly, for mid-age and old drivers, drowsiness is accompanied by more than 3-folds of increase (OR=3.4 and OR=3.26) in the odds of a more severe injury compared to non-distracted mid-age and non-distracted old drivers respectively.

Table 3: Injury severity results for distraction type and driver age

Comparisons	Estimate*	OR	95% CI
Distracted young driver vs. non-distracted young driver			
Inattention	-0.10	0.91	0.90 – 0.92
In-vehicle sources	0.20	1.22	1.19 – 1.26
Passenger related distraction	0.10	1.10	1.06 – 1.13
Dialling or texting on cell phone	0.66	1.94	1.85 – 2.02
Talking on cell phone	-0.09	0.91	0.87 – 0.96
External distraction	-0.67	0.51	0.51 – 0.50
Drowsiness	0.45	1.58	1.51 – 1.64
Distracted mid-age driver vs. non-distracted mid-age driver			
Inattention	-0.18	0.84	0.83 – 0.84
In-vehicle sources	0.50	1.65	1.62 – 1.68
Passenger related distraction	0.41	1.51	1.47 – 1.54
Dialling or texting on cell phone	0.28	1.33	1.26 – 1.39
Talking on cell phone	0.19	1.21	1.16 – 1.27
External distraction	-0.07	0.93	0.92 – 0.95
Drowsiness	1.22	3.40	3.30 – 3.50
Distracted old driver vs. non-distracted old driver			
Inattention	-0.07	0.93	0.92 – 0.94
In-vehicle sources	0.56	1.75	1.65 – 1.85
Passenger related distraction	0.36	1.44	1.24 – 1.67
Dialling or texting on cell phone	1.26	3.51	2.56 – 4.82
Talking on cell phone	0.76	2.14	1.85 – 2.48
External distraction	-0.59	0.56	0.52 – 0.59
Drowsiness	1.18	3.26	2.27 – 4.69

* All estimates are significant at $p<.0001$

Within the mid-age drivers group, inattention (OR=0.84) and external distraction (OR=0.93) appears to be protective. However, unlike the young drivers group, talking on cell phone (OR=1.21) results in a more severe crash compared to no distractions. Other distractions, i.e., in-vehicle sources (OR=1.65), passengers (OR=1.51), and dialling or texting on the cell phone (OR=1.33), are associated with higher odds of severe injuries. In crashes that involve an old driver, odds of having severe injuries is less if the old driver is inattentive (OR=0.84) or distracted by things outside of the vehicle (OR=0.93) than crashes which involve a non-distracted old driver. Dialling or texting (OR=3.51) and talking on the cell phone (OR=2.14) appear to be the most harmful distraction types for old drivers in regards to a severe crashes. Crashes involving old drivers who are distracted by in-vehicle sources (1.75) or passengers (1.44) are also associated with higher odds of resulting in more severe crashes.

Figure 1 helps visualize the results discussed above by comparing different age-distraction combinations to a single baseline: non-distracted mid-age drivers. When there is no distraction involved in a crash, crashes involving young drivers are associated with higher odds of severe crash injuries compared to crashes involving old or mid-age drivers. Distractions appear to have more profound effects on old drivers than young and mid-age drivers. To summarize, inattention and external distractions have consistent effects across age groups. They are associated with a reduced likelihood of severe injuries. Dialling or texting on the cell phone is particularly harmful in crashes involving old and young drivers. On the other hand, talking on the cell phone appears to be protective for young drivers but harmful for old drivers.

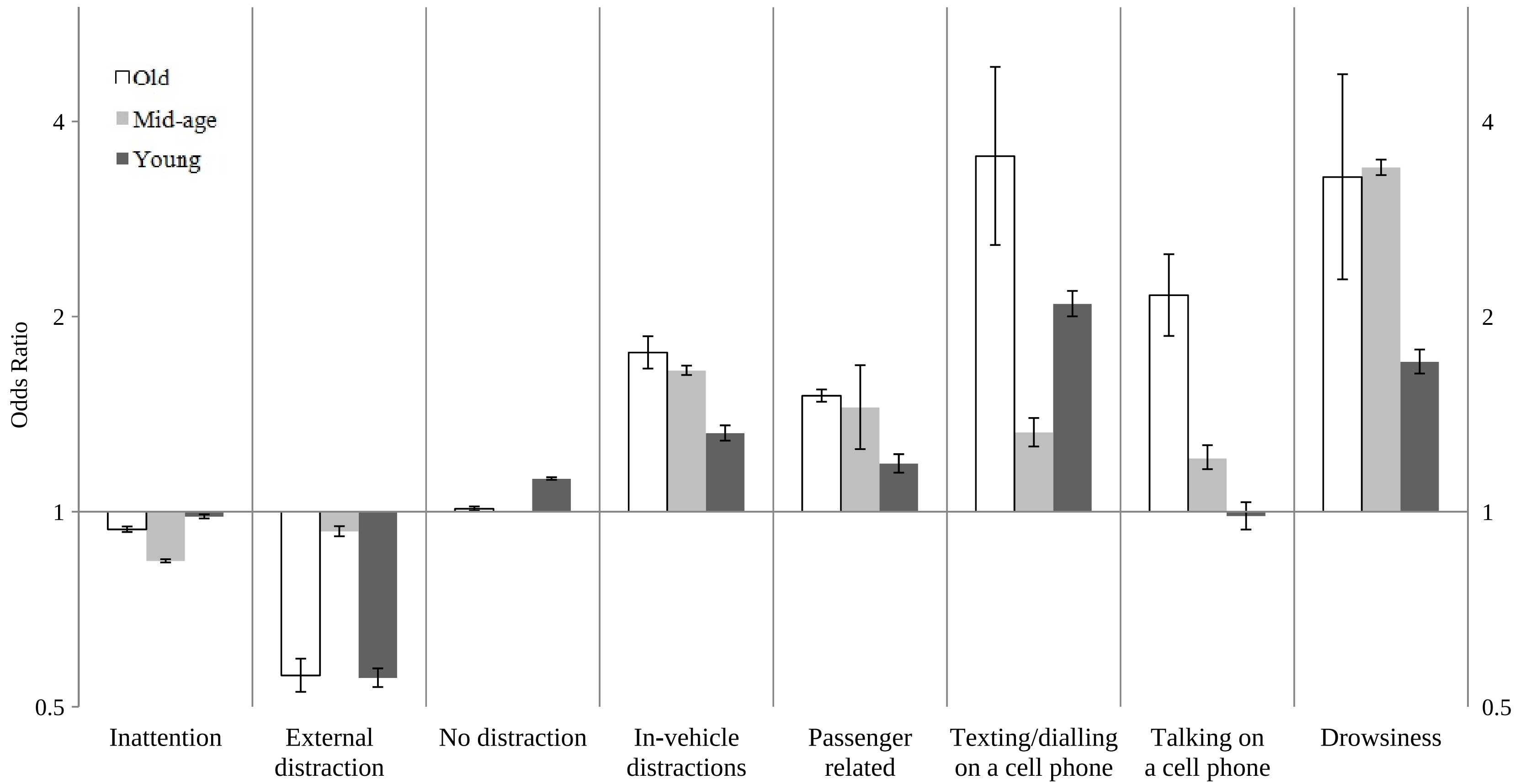

Figure 1: Injury severity odds ratios for different distraction and driver age groups (baseline: non-distracted mid-age driver; error bars indicate 95% confidence intervals)

Chapter 4
Study Two: Effects of Distractions and Driver's Age on Crash Type

By employing a multinomial model, this study aims to estimate whether driver distraction, driver age, or their interaction have significant effects on crash types. The dependent variable utilized is the type of crash. In addition to the main and interaction terms of distraction type and driver age, the model statistically controls for other factors such as environmental and crash-specific factors. A multinomial model is an extension of the binary logistic model, but has the capability of treating multi-level categorical response variables that have no apparent inherent order. Like the logistic model, both numerical and categorical explanatory variables can be included in the model.

4.1 Data Description

GES data from 2003 to 2008 were also used in this model. Given that rear-end, angular, and singular crashes constitute the majority of crashes in the GES sample (81%), this study focused on these three crash types. The dataset used in this study is different from that used in the previous model (Study One) in two ways. First, because this study concerns only crash type, passenger information is not included. Second, for the purpose of simplifying inferences, the previous analysis (Study One) utilized only two-vehicle direct crashes. The current study includes singular crashes in addition to two-vehicle direct crashes (i.e., rear-end and angular crashes). However, the struck vehicles in rear-end crashes are excluded given that the following (or striking) vehicle is generally at fault in rear-end crashes. Thus, drivers in rear-end crashes refer to those who crash into a lead vehicle due to improper braking or following too close.

Drivers in singular crashes refer to those who collide with a fixed object on the road or on the side of the road. Unlike previous research on this topic which did not distinguish struck and striking vehicles (Ghazizadeh & Boyle, 2009; Neyens & Boyle, 2007), angular crashes were separated into two categories: striking vehicle and struck vehicle. The striking vehicle's front hits the struck vehicle, whereas the struck vehicles are hit from the side.

4.2 Descriptive Statistics

A weighted total of 4,497,107 crashes (38,669 un-weighted) and 6,228,231 drivers (53,555 un-weighted) were included in this study. The most common crash type is angular (40%), followed by rear-end (39%), with the least common being singular (21%).

Table 4: Crash type data: weighted frequencies of drivers that were involved in a crash (percentage in row total) by driver age and crash type

Crash type	Driver's age			Row total
	Young	Mid-age	Old	
Singular crash	397,791 (41.9%)	519,495 (54.7%)	32,927 (3.47%)	950,213
Rear-end crash (striking)	609,546 (34.5%)	1,085,935 (61.5%)	70,732 (4.00%)	1,766,213
Angular crash (striking)	500,171 (28.1%)	1,151,368 (64.7%)	129,142 (7.25%)	1,780,681
Angular crash (struck)	466,506 (27.0%)	1,139,244 (65.8%)	125,373 (7.24%)	1,731,123
All drivers (column total)	1,974,014 (31.7%)	3,896,042 (62.6%)	358,175 (5.75%)	6,228,231

* Percentage in row total

Table 4 is based on the weighted count of drivers in the dataset. It presents each age group's proportion in the entire driver sample (last row percentages) and each age group's proportion within a particular crash type (cell percentages excluding the last row). Mid-age drivers represent the largest proportion at 62.6%, followed by young drivers at 31.7%, and finally old drivers at 5.75%. It should be noted that the data from same angular crashes are repeated twice in Table 4: for drivers in the striking vehicle and for drivers in the struck vehicle. One would expect that the numbers for striking and struck drivers should be the same, however, due to missing variables for some of the drivers, not all drivers were included in the analysis. In particular, it appeared that the distraction type information was missing especially for drivers in the struck vehicle.

Compared to their overall proportion (31.7%), young drivers represent a larger portion in singular (41.9%) and rear-end (34.5%) crashes. Mid-age and old drivers have larger proportions in angular crashes (64.7% and 65.8% for mid-age, and 7.25% and 7.24% for old) than they do in the entire driver sample (62.6% for mid-age and 5.75% for old). These trends are more apparent in Figure 2, where proportions are calculated in a different way as explained below.

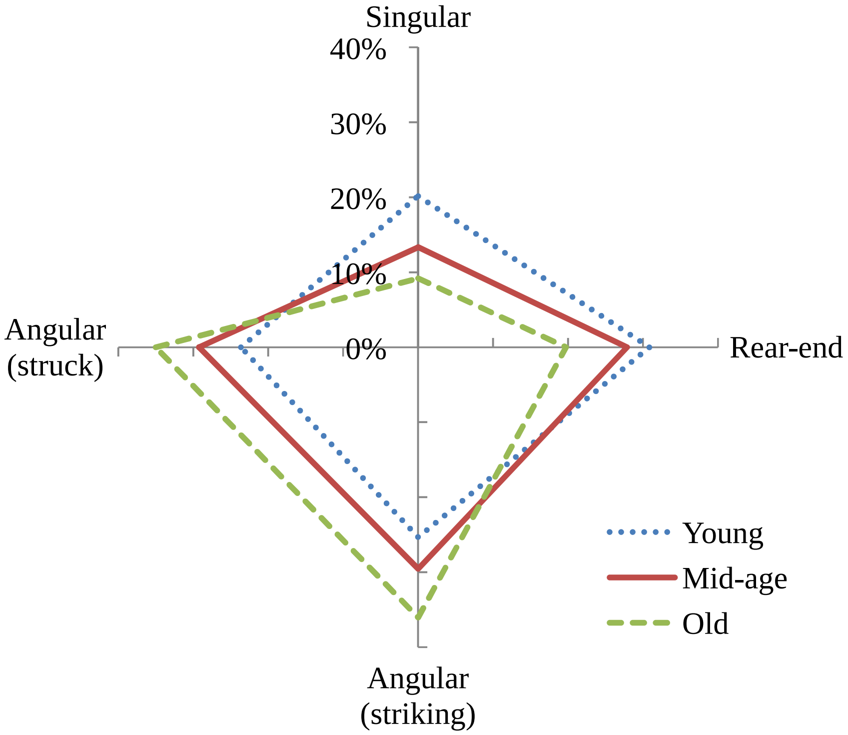

Figure 2: Rate of different crash types observed for young, mid-age, and old drivers

Percentages in Figure 2 represent the proportion of each crash type within a particular age group. Thus, the four corners of each series (young, mid-age, and old) add up to 100%. The trends described in the previous paragraph are also apparent in this figure: one can see a shift from the first quadrant (singular and rear-end) to the third quadrant (angular striking and angular struck) as age increases. The underlying reasons for this trend cannot be investigated within this thesis given that crash reports are collected after the occurrence of events; thus cannot be used to assess crash risks. Future research should investigate the reasons for this trend.

4.3 Multinomial Model

The model covariates are the same as the ordered logit model described in Chapter Three with only a few exceptions. First of all, occupant information is not included in the model; only the driver's information is included. Moreover, crash type was included as a covariate in Chapter Three, whereas it is the dependent variable in this multinomial logit model. The definitions and levels of the covariates, such as age, are kept the same.

A multinomial model was built using the MLOGIT procedure in LIMDEP version 8. Based on the GES data, collision type is classified into three levels: single-vehicle, rear-end, and angular (striking or struck). The model predicts the odds of being involved in a particular type of crash given that a crash has occurred. Therefore, the results should not be interpreted as crash risk of a certain collision type.

A multinomial model provides a strategy that takes into account the nominal nature of data (Stokes, et al., 2000) and is represented with a set of equations as:

$$\ln\left[\frac{p_1}{p_0}\right] = \beta_{01} + \mathbf{\beta X} \qquad (4)$$

$$\ln\left[\frac{p_2}{p_0}\right] = \beta_{02} + \boldsymbol{\beta}\mathbf{X} \qquad (5)$$

$$\ln\left[\frac{p_3}{p_0}\right] = \beta_{03} + \boldsymbol{\beta}\mathbf{X} \qquad (6)$$

where p_0 represents the probability of a rear-end crash, p_1 represents the probability of a singular crash, p_2 represents the probability of an angular-striking crash, and p_3 represents the probability of an angular-struck crash. Thus, the equations represent the log-odds of collision types for: "single-vehicle crash" versus "rear-end crash" (eqn. 4); "angular striking" versus "rear-end crash" (eqn. 5); "angular struck" versus "rear-end crash" (eqn. 6). β_{0i} represents the intercept and $\boldsymbol{\beta}$ is the matrix of coefficient estimates for predictor variables, $\mathbf{X}$.

Similar to Study One, a confidence level of 99.9% (or $\alpha = .001$) was adopted for determining statistical significance. The odds ratios are more complex in a multinomial model than they are in an ordinal logit model given that each covariate is assigned a different coefficient ($\boldsymbol{\beta}_i$) in the model equations (eqns 4, 5, and 6). In an ordinal logit model, the effect of a covariate on the response variable (e.g., injury severity) is assumed to be independent of the categories. That is, the odds are assumed constant for all categories. For example, a covariate either increases injury severity or decreases it. A multinomial model would suggest that a covariate can increase the likelihood of a mid-level injury while decreasing the likelihood of a fatal injury.

In the results section, three odds ratios will be reported for each covariate as follows: Controlling for all other covariates,

1) the odds of a singular crash over a rear-end crash given covariate level A (e.g., alcohol involved) divided by the same odds given covariate level B (e.g., no alcohol

involved). Odds here are calculated as the probability of a singular crash divided by the probability of a rear-end crash. Thus,

$$Odds\ Ratio(1) = \frac{\frac{\text{P(a singular crash|alcohol)}}{\text{P(a rear − end crash|alcohol)}}}{\frac{\text{P(a singular crash|no alcohol)}}{\text{P(a rear − end crash|no alcohol)}}}$$

2) the odds of an angular-striking crash over a rear-end crash given covariate level A (e.g., alcohol involved) divided by the same odds given covariate level B (e.g., no alcohol involved). Odds here are calculated as the probability of an angular-striking crash divided by the probability of a rear-end crash.

$$Odds\ Ratio(2) = \frac{\frac{\text{P(an angular − striking crash|alcohol)}}{\text{P(a rear − end crash|alcohol)}}}{\frac{\text{P(an angular − striking crash|no alcohol)}}{\text{P(a rear − end crash|no alcohol)}}}$$

3) the odds of an angular-struck crash over a rear-end crash given covariate level A (e.g., alcohol involved) divided by the same odds given covariate level B (e.g., no alcohol involved). Odds here are calculated as the probability of an angular-struck crash divided by the probability a rear-end crash.

$$Odds\ Ratio(3) = \frac{\frac{\text{P(an angular − struck crash|alcohol)}}{\text{P(a rear − end crash|alcohol)}}}{\frac{\text{P(an angular − struck crash|no alcohol)}}{\text{P(a rear − end crash|no alcohol)}}}$$

Therefore, an odds ratio (3) greater than 1 would suggest that the odds of observing an angular-struck crash over a rear-end crash when alcohol is involved is higher than that when alcohol is not involved. It should be noted that an odds ratio greater than 1 here does not necessarily mean that alcohol increases the probability (or likelihood) of singular crashes.

4.4 Model Results

Table 5: Crash type results: model coefficient estimates and p-values

	Eqn. 4 **singular vs. rear-end**		Eqn. 5 **angular-striking vs. rear-end**		Eqn. 6 **angular-struck vs. rear-end**	
Variable	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value
Constant	-1.081	<.0001	0.989	<.0001	0.957	<.0001
Rural	0.397	<.0001	0.017	n.s.; .58	-0.025	n.s.; .43
Highway	0.187	.0001	-1.275	<.0001	-1.573	<.0001
Non daylight	1.016	<.0001	0.346	<.0001	0.295	<.0001
Bad weather	0.682	<.0001	0.227	<.0001	0.172	<.0001
Speeding	0.120	.0007	-1.914	<.0001	-3.019	<.0001
Alcohol	0.831	<.0001	-0.275	.0001	-0.274	.0002
Female	0.121	.0002	0.097	.0004	0.154	<.0001
Intersection	-0.747	<.0001	-0.174	n.s.; .01	-0.251	.0007
Curvy road	1.854	<.0001	-0.244	<.0001	-0.242	<.0001
Inattention						
Young	-1.279	<.0001	-1.114	<.0001	-0.919	<.0001
Mid-age	-1.455	<.0001	-1.027	<.0001	-1.017	<.0001
Drowsiness						
Young	1.869	<.0001	-2.175	<.0001	-2.788	<.0001
Mid-age	1.043	<.0001	-2.057	<.0001	-2.681	<.0001
Passenger-related distraction						
Young	0.344	n.s.; .13	-1.803	<.0001	-2.162	<.0001
Mid-age	-0.236	n.s.; .20	-2.092	<.0001	-3.109	<.0001
In-vehicle distraction						
Young	0.202	n.s.; .08	-2.059	<.0001	-3.027	<.0001
Mid-age	0.147	n.s.; .89	-2.294	<.0001	-3.692	<.0001
Talking on a cell phone						
Young	-0.576	n.s.; .03	-1.181	<.0001	-1.830	<.0001
Mid-age	0.052	n.s.; .83	-1.489	<.0001	-1.376	<.0001
Texting/dialling on a cell phone						
Young	-0.356	n.s.; .43	-4.204	.0007	-2.117	<.0001
Mid-age	-0.127	n.s.; .77	-1.428	n.s.; .002	-3.584	n.s.; .002
External distraction						
Young	-1.679	<.0001	-2.713	<.0001	-3.679	<.0001
Mid-age	-1.936	<.0001	-2.759	<.0001	-3.027	<.0001

* n.s. stands for not significant at α=.001 level

The model coefficients and corresponding p-values are presented in Table 5. The model includes rear-end, singular, angular-striking, and angular-struck crashes as four possible realizations of the response variable. It should be noted that various coefficient estimates associated with old drivers were found to be nonsignificant in the model. This trend was likely due to the very few number of observations within corresponding categories. Thus, old driver data were not included in the final model.

Table 6: Frequencies of actual and predicted model outcomes

	Predicted				
Actual	Rear-end	Singular	Angular-striking	Angular-struck	Row Total
Rear-end	**438,910**	112,293	128,905	270,105	950,213
Singular	377,826	**939,935**	186,462	261,991	1,766,213
Angular-striking	229,524	126,848	**443,539**	980,770	1,780,681
Angular-struck	188,862	104,589	420,586	**1,017,086**	1,731,123

Table 6 presents the confusion matrix specifying the frequencies of actual and predicted outcomes. Forty-six percent of the rear-end crashes (438,910 / 950,213), 53% of the singular crashes, 25% of angular-striking, and 59% of the angular stuck crashes were correctly predicted. The lower accuracy rate for angular-striking crashes may be due to the model controlling for a number of environmental variables that were identical for striking and struck vehicles involved in the same angular crash. Since the majority of the confusion is between angular striking and struck crashes, building two different models separating these crash types may increase the accuracy rates (e.g., first model with three outcomes: rear-end, singular, and angular-striking; second model with three outcomes: rear-end, singular, and angular struck).

Table 7 reports the odds ratio calculated based on the model coefficients. It indicates that driving in rural settings (as opposed to urban) increases the odds of a singular crash by 49% compared to rear-ending another vehicle (OR = 1.49). Thus, driving in rural settings shifts crash types towards singular crashes, while no significant effects are found for angular crashes when they are compared to rear-end crashes. Female drivers (as opposed to male drivers) have increased odds of being involved in singular (OR=1.13) and angular crashes (OR=1.10 for striking, OR=1.17 for struck) compared to rear-end crashes.

Table 7: Crash type results for driver age and distraction

	Eqn. 4 **singular vs. rear-end**		Eqn. 5 **angular-striking vs. rear-end**		Eqn. 6 **angular-struck vs. rear-end**	
Comparisons	OR	95% CI	OR	95% CI	OR	95% CI
Rural vs. urban	1.49	1.44 – 1.54	n.s.*; 1.02	0.99 – 1.05	n.s.*; 0.97	0.94 – 1.01
Highway vs. non-highway	1.21	1.15 – 1.27	0.28	0.26 – 0.30	0.21	0.19 – 0.22
Non-daylight vs. daylight	2.76	2.66 – 2.86	1.41	1.37 – 1.46	1.34	1.30 – 1.39
Bad vs. normal weather	1.98	1.90 – 2.06	1.25	1.21 – 1.30	1.19	1.14 – 1.24
Speeding vs. non-speeding	1.13	1.09 – 1.17	0.15	0.14 – 0.15	0.05	0.05 – 0.05
Alcohol vs. non-alcohol	2.30	2.15 – 2.45	0.76	0.71 – 0.82	0.76	0.71 – 0.82
Female vs. male	1.13	1.09 – 1.17	1.10	1.07 – 1.13	1.17	1.13 – 1.20
Intersection vs. non-intersection	0.47	0.44 – 0.51	0.84	0.79 – 0.90	0.78	0.72 – 0.84
Curvy vs. straight road	6.38	6.10 – 6.68	0.78	0.74 – 0.83	0.79	0.74 – 0.83
Distracted young vs. non-distracted young						
Inattention	0.28	0.26 – 0.30	0.33	0.31 – 0.35	0.40	0.38 – 0.42
Drowsiness	6.48	5.65 – 7.43	0.11	0.09 – 0.15	0.06	0.04 – 0.09
Passenger-related	1.41	1.12 – 1.77	0.17	0.12 – 0.22	0.12	0.08 – 0.16
In-vehicle	1.22	1.09 – 1.37	0.13	0.11 – 0.15	0.05	0.04 – 0.06
Talking on a cell phone	0.56	0.43 – 0.74	0.31	0.24 – 0.39	0.16	0.12 – 0.22
Texting/dialling on a cell phone	n.s.*; 0.70	0.45 – 1.09	0.02	0.00 – 0.05	0.12	0.07 – 0.20
External distraction	0.19	0.16 – 0.22	0.07	0.05 – 0.08	0.03	0.02 – 0.03
Distracted mid-age vs. non-distracted mid-age						
Inattention	0.23	0.22 – 0.25	0.36	0.34 – 0.37	0.36	0.35 – 0.38
Drowsiness	2.84	2.57 – 3.13	0.13	0.11 – 0.15	0.07	0.05 – 0.09
Passenger-related	n.s.; 0.79	0.66 – 0.95	0.12	0.10 – 0.15	0.05	0.03 – 0.06
In-vehicle	n.s.; 1.01	0.91 – 1.13	0.10	0.09 – 0.12	0.03	0.02 – 0.03
Talking on a cell phone	n.s.; 1.05	0.83 – 1.34	0.23	0.17 – 0.30	0.25	0.19 – 0.33
Texting/dialling on a cell phone	n.s.; 0.88	0.57 – 1.37	0.24	0.15 – 0.38	0.03	0.01 – 0.09
External distraction	0.14	0.12 – 0.17	0.06	0.05 – 0.07	0.05	0.04 – 0.06

* n.s. stands for not significant at α=.001 level

Non daylight (as opposed to daylight) increases the odds of having a singular crash by almost 3-fold compared to a rear-end crash (OR=2.76). Under this condition, the odds of angular crashes over rear-end crashes are also increased (OR=1.41 for striking, OR=1.34 for struck). Bad weather has similar effects as non daylight: the odd ratios for singular, angular-striking, and angular-struck crashes over rear-end crashes are 1.98, 1.25, and 1.19, respectively. At an intersection (as opposed to non-intersection), the odds of rear-end crashes increase compared to singular (OR=1/0.47 =2.11) and angular crashes (OR=1/0.84=1.19 for striking, OR=1/0.78=1.29 for struck).

Driving on the highway, speeding, alcohol, and driving on curvy roads have similar effects on crash types. In particular, they all increase the odds of singular crashes over rear-end crashes (OR=1.21; 1.13; 2.30; 6.39, respectively). On the other hand, the odds of striking another vehicle or being struck in an angular crash are less over rear-ending another vehicle (OR=0.28 and 0.21 for highway; 0.15 and 0.05 for speeding; 0.76 and 0.76 for alcohol; 0.78 and 0.79 for curvy roads). In general, our findings on these variables which were controlled for in our model are in line with previous studies (Ghazizadeh & Boyle, 2009; Neyens & Boyle, 2007). Due to the complexity of the age distraction interaction, the following model results will be interpreted through visualization of different crash rates.

<u>Inattention:</u>

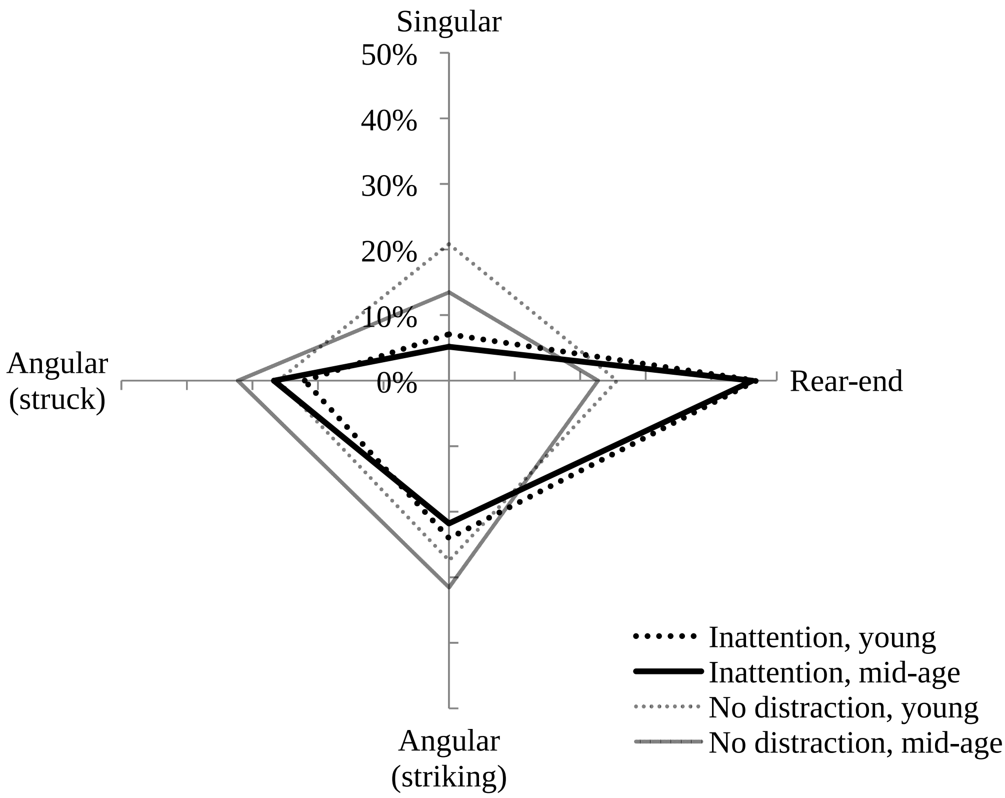

Figure 3: Rate of different crash types observed for inattentive young and mid-age drivers

As illustrated by Figure 3, inattention impacted young and mid-age drivers in a similar way. Two apparent changes are the decrease in the rate of singular crashes and an increase in the rate of rear-end crashes. The singular crash rates are reduced by more than half, while the rear-end crash rates are almost doubled for both age groups. These effects are significant as reported in Table 5 and Table 6. Neyens and Boyle (2007) found the same effect for teenager drivers.

Drowsiness:

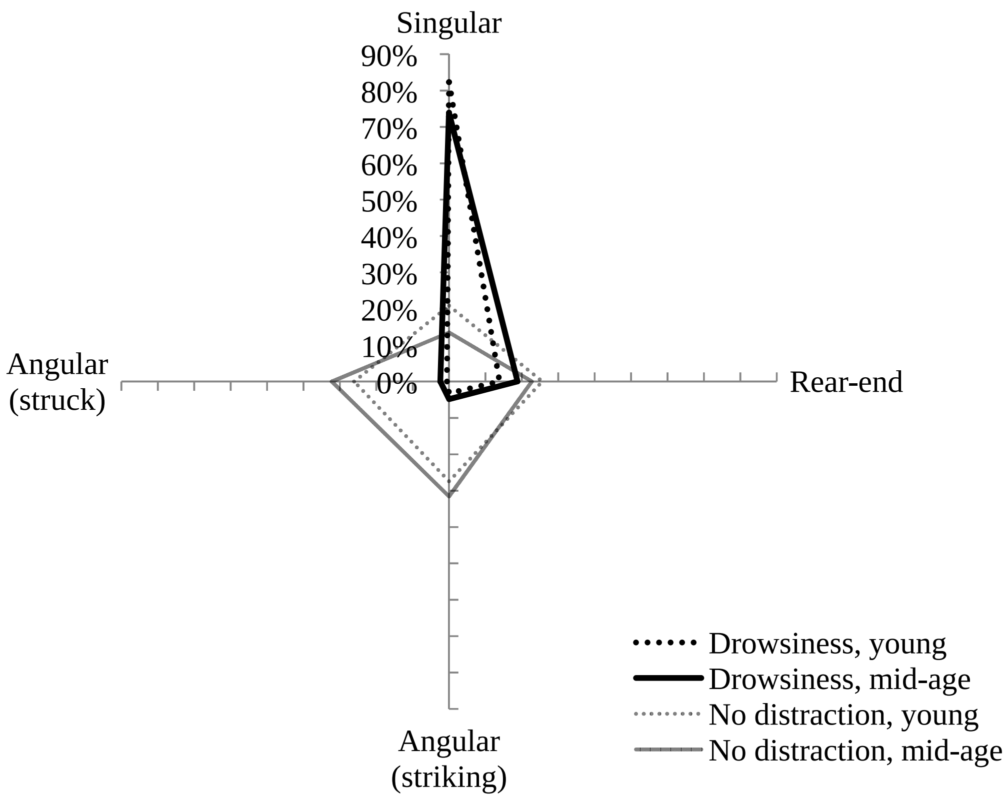

Figure 4: Rate of different crash types observed for drowsy young and mid-age drivers

Drowsy driving increases the rate of singular crashes dramatically (compared to rear-end crashes: OR=6.48 for young drivers, OR=2.84 for mid-age drivers), reducing the rate of rear-end and angular crashes. Previous literature also suggests that the majority of drowsy-driving crashes are singular run-off the road crashes (Pack, et al., 1995).

<u>Passenger-related distraction:</u>

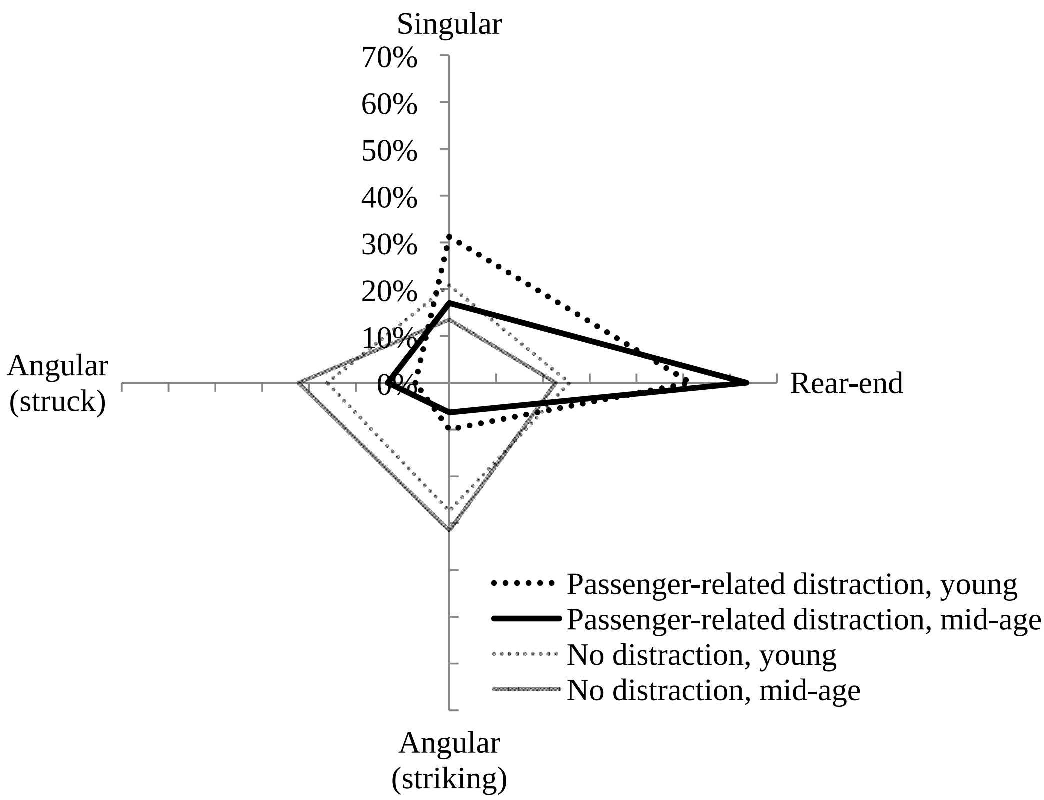

Figure 5: Rate of different crash types observed for young and mid-age drivers distracted by passengers

Passenger-related distractions appear to increase the rate of singular and rear-end crashes. However, there seems to be an age-distraction interaction. Specifically, the increase in the rate of singular crashes is larger for young drivers, whereas the increase in the rate of rear-end crashes is larger for mid-age drivers. Our observed effects for young and mid-age drivers contradict the results of Ghazizadeh and Boyle (2009). Specifically, they indicated that angular crash rates significantly increase with passenger-related distractions; whereas we found the reverse trend. The mismatch in findings might be due to the additional covariates used in Ghazizadeh and Boyle (2009).

In-vehicle distraction:

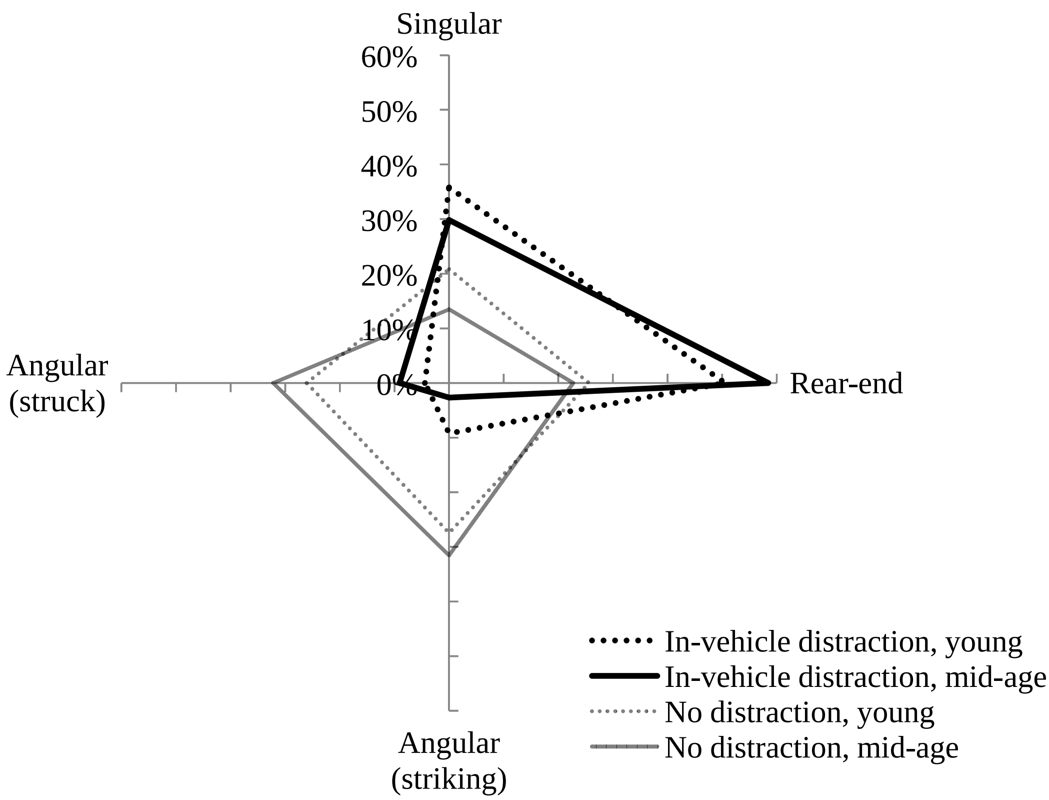

Figure 6: Rate of different crash types observed for young and mid-age drivers distracted by in-vehicle sources

Similar to passenger-related distractions, in-vehicle distractions appear to increase the rate of singular and rear-end crashes for both age groups. There also appears to be a distraction-age interaction, with rear-end crash rates increasing more for mid-age drivers and singular crash rates increasing more for young drivers. The results observed here are in-line with Neyens and Boyle (2007) and Ghazizadeh and Boyle (2009).

Talking on a cell phone:

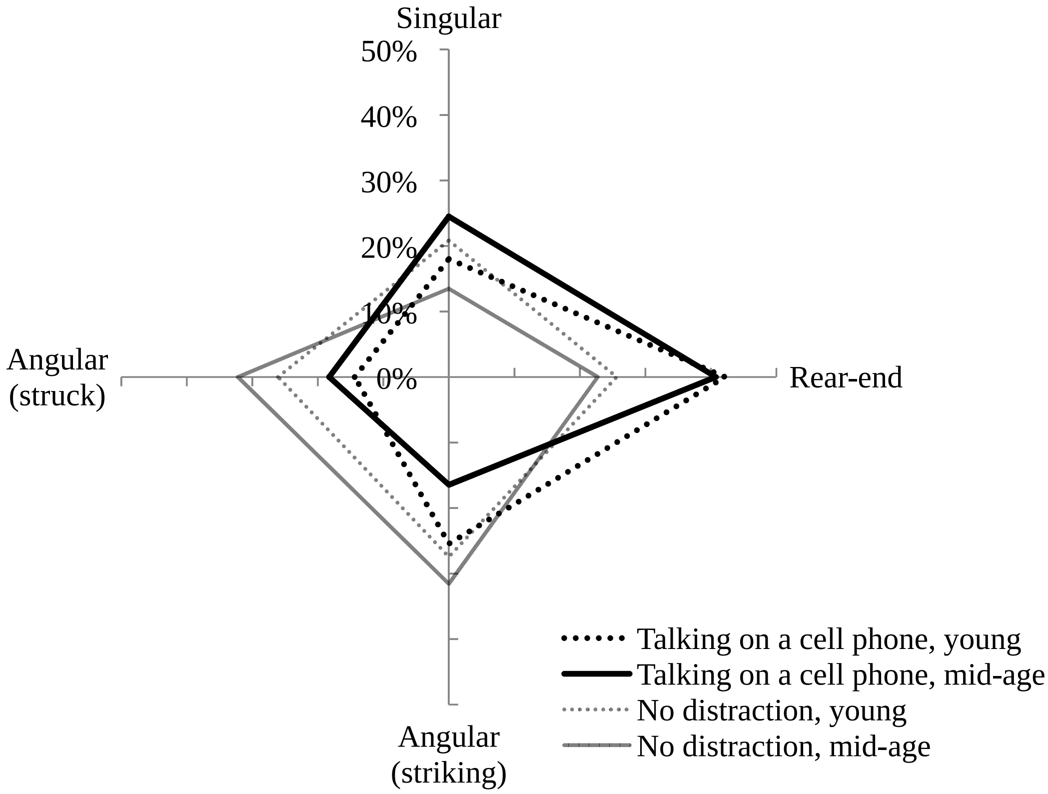

Figure 7: Rate of different crash types observed for young and mid-age drivers who were talking on a cell phone

Talking on a cell phone is associated with increased rates of rear-end crashes for both age groups. Mid-age drivers also have an increased rate of singular crashes, and a decreased rate of angular-striking crashes, whereas these trends are not apparent for young drivers.

Texting/dialling on a cell phone:

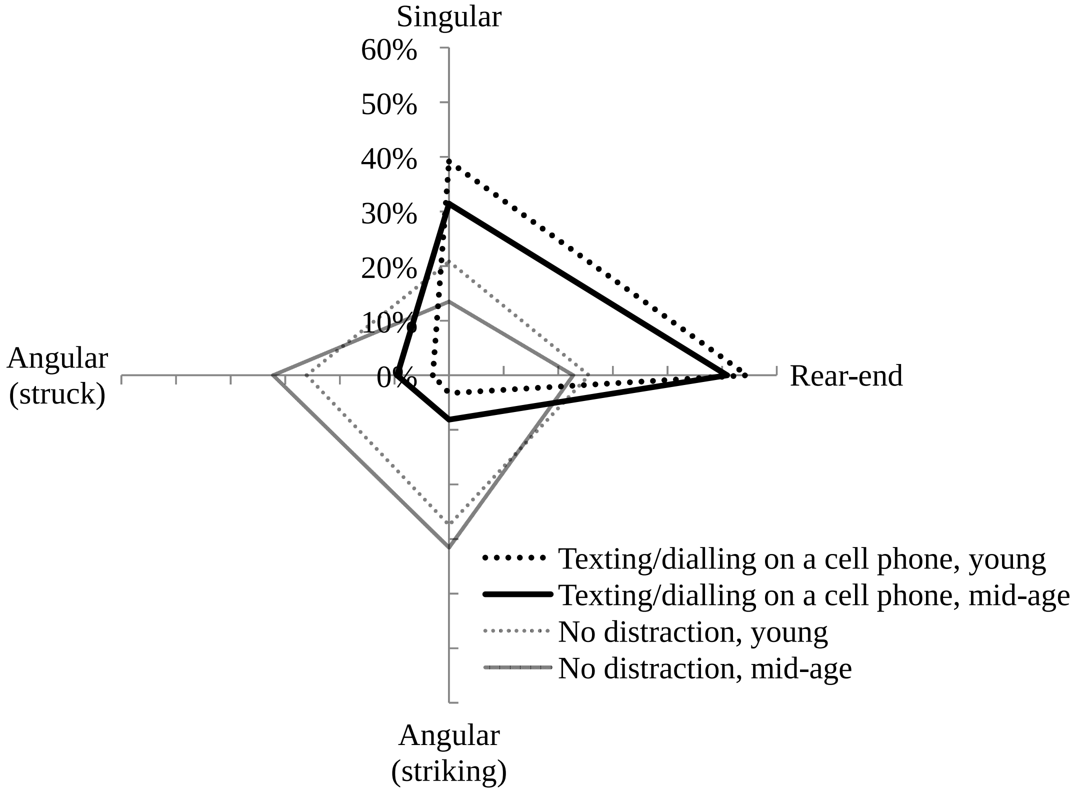

Figure 8: Rate of different crash types observed for young and mid-age drivers who were texting/dialling on a cell phone

Compared to talking on a cell phone, texting/dialling on a cell phone exhibited different effects for young drivers. While we did not observe significant changes in singular and angular-striking crash rates for young drivers who were talking on a cell phone, we found that when young drivers are texting/dialling on a cell phone, singular crash rates increase and angular-striking crash rates decrease.

External distraction:

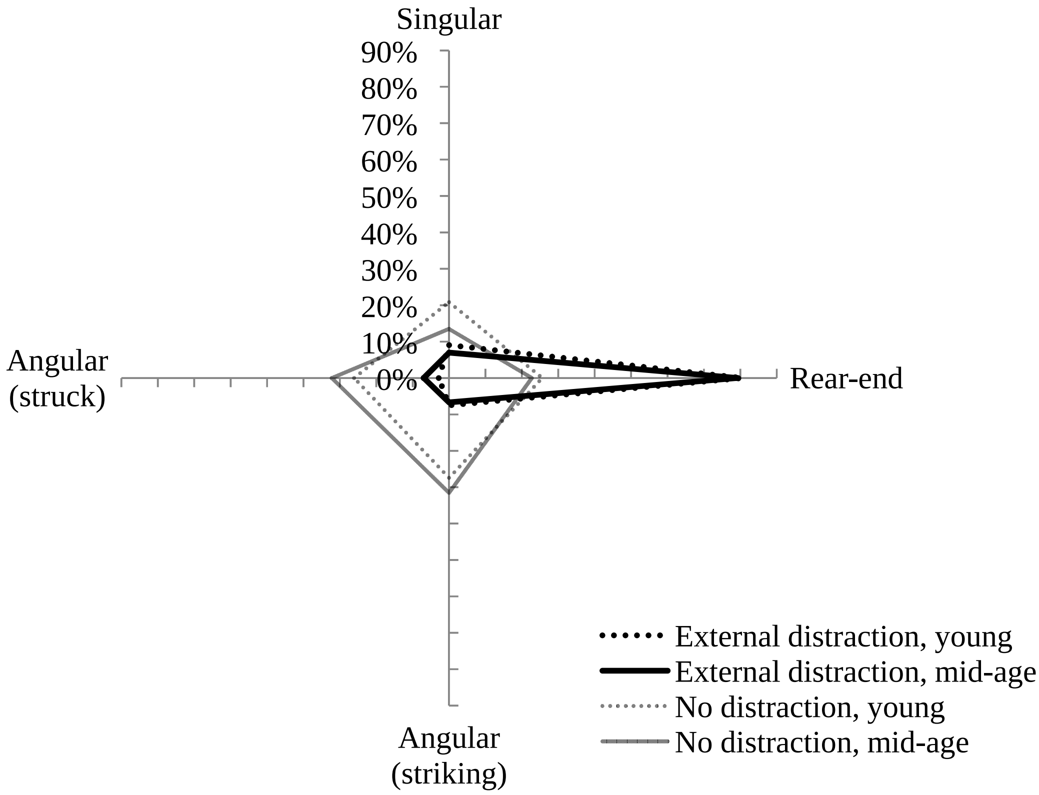

Figure 9: Rate of different crash types observed for young and mid-age drivers distracted by an external source

External distractions appear to have the same effects for young and mid-age drivers, with a dramatic increase in rear-end crash rates (see the extremely low odds ratios in the external distraction row for both age groups). There have been no other studies which compared external distractions to other distraction types. In general, all distraction types except drowsiness are associated with an increase in rear-end crash rates. The largest increase is observed for external distractions. Many of the distraction types also appear to increase singular crash rates, with the exception of inattention (a reduction is observed), passenger-related distractions (no major changes observed for mid-age drivers), talking on a cell phone (no major changes observed for young drivers), and external distractions (a reduction is observed). In general, angular crash rates appear to decrease for all distraction types with the exception of inattention (no major changes observed for young drivers).

Chapter 5
Discussion

5.1 Distractions and Their Effects on Crash Outcomes

5.1.1 Passenger-Related Distractions and Talking on a Cell Phone

Passenger-related distractions have been widely examined. In crash report studies, the presence of passengers in a crash has been shown to increase the likelihood of more severe injuries, not only for passengers themselves but also for the drivers (Kockelman & Kweon, 2002; Neyens & Boyle, 2008). Doherty et al. (1998) examined the role of passengers in police-reported crashes from 1988, comprising of 306,000 drivers aged between 16 and 59 years old. Their descriptive statistical analysis revealed that when young drivers were carrying passengers, they had a higher crash rate than when they were driving alone. Another study by Rice et al. (2003) also confirmed this finding. However, a problem with passenger distraction research is that they either did not distinguish age or emphasize young and teenage drivers. Older drivers are also a high-risk group and attention should also be given to this group. The results of Study One indicate that passengers increase the likelihood of more severe injuries, however this effect is smallest for young drivers. There is a more dramatic effect of passengers on the resulting severities of crashes involving mid-age and/or older drivers.

In a statistical study on occupant injuries, where injury data were collected from hospital attendance records and cell phone usage data were collected from phone records, talking on cell phones was found to be associated with an increase in more severe injuries (McEvoy et al., 2005). Study One results also suggest that when a mid-age or an old driver is talking on a cell phone, people involved in the crash have higher odds of sustaining severe injuries, while the opposite effect was found for young drivers. Although it may appear that Study One's result on young drivers contradicts the results of Neyens and Boyle (2008), who found that cell-phone related distractions significantly increase injury severities in teenage driver crashes, the demographic they used (teenagers as opposed to young drivers) and their operationalization of cell-phone related distractions (talking and dialling/texting on cell phones were grouped together) are different than those used in this thesis.

These two types of distractions, conversing with a passenger and on a cell phone, share some common traits – e.g., both involve talking with another person. However, there are still some differences. For example, a hand-held cell phone may induce a manual distraction (hand off the steering wheel) and a passenger may induce a visual distraction (looking towards the passenger). Study Two's results indicate that passenger-related distractions and talking on a cell phone increases the odds of rear-end crashes for young and mid-age drivers. Moreover, this effect appears to be larger for passenger-related distractions than for talking on a cell phone. As presented in Chapter Two, existing literature, although relatively limited, indicates that conversing on the phone and with a passenger have comparable effects on driving behaviour and performance (e.g., Laberge et al. (2004), Nunes and Recarte (2002)). There is some evidence that talking on a cell phone may induce compensatory behaviours that are larger in magnitude. For example, a simulator study revealed that subjects maintain greater following distances when they are talking on a cell phone than they do when conversing with a passenger (Amado & Ulupinar, 2005). Further, research shows that more drivers report that they do feel the need to slow down or maintain larger following distances when they are talking on their cell phones compared to when they are distracted by passengers (Baker & Spina, 2007). Greater following distances and reduced speeds with cell phone conversations may translate to a dampened effect on the increase in rear-end crashes, potentially explaining the findings of Study Two.

Moreover, in Study One and Study Two, the crash outcomes of these two distractions appear to have interaction effects with age. Specifically, young drivers' singular crash rates increases dramatically with passenger-related distractions, while mid-age drivers appear to have a milder increase in singular crash rates. On the other hand, mid-age drivers' singular crash rates appear to increase when they are talking on cell phones, while young drivers appear to have decreased singular crash rates. These observations provide motivations to study different age groups' driving performance in the presence of different distractions. Although such research is extensively conducted for young drivers, older drivers need no less attention.

5.1.2 In-Vehicle Distractions and Dialling/Texting on a Cell Phone

Performing in-vehicle distracting tasks, such as adjusting on-board entertainment and A/C systems, eating, drinking, and smoking, often requires a hand off the wheel or eyes off the road. The results of Study One indicate in-vehicle distractions are associated with an increase in injury severities. This effect strengthens as age grows. Study Two's results suggest that driver distracted by in-vehicle sources run into proportionately more singular and rear-end crashes. Both Ghazizadeh and Boyle (2009) and Neyens and Boyle (2007)'s results are in accordance with this result. In addition, this effect is larger for mid-age drivers with a more dramatic increase of rear-end crash rates for this age group.

Results from Study One indicate that older drivers are affected the most from in-vehicle distractions with regards to occupant injury severities and rear-end crash involvement. On the other hand, older drivers seem to be less likely to engage in such activities, as evidenced by Table 1.

The combination of these trends implies a need to design mitigation strategies to help older drivers better handle in-vehicle distractions rather than discouraging them from engaging in these activities, for they already seem to restrain themselves, i.e., both mid-age and older drivers appear to have smaller involvement rates in in-vehicle distraction than young drivers do (Table 1). On the other hand, the results indicate that young drivers are affected by in-vehicle distractions on a much smaller magnitude compared to other age groups. Possible explanations could be that young drivers are able to handle such distractions better, or they perform relatively simpler tasks than older drivers. Further experiments are needed to assess if young drivers' performance degradation is less compared to older drivers, when performing in-vehicle distracting tasks.

Effects of dialling/texting on a cell phone were expected to be similar to that of in-vehicle distractions. Such an expectation was generally true for rear-end crashes. However, there was also an age interaction effect for in-vehicle distractions which was not observed for dialling/texting on a cell phone, with in-vehicle distractions affecting mid-age drivers more than young drivers in terms of rear-end crash rates. Further, for dialling/texting on a cell phone younger driver crashes had higher odds of a severe outcome than mid-age driver crashes, whereas for in-vehicle distraction mid-age driver crashes had the higher odds. A possible reason is that younger drivers may be exposed to text messaging longer than mid-age drivers. Although there is no literature supporting this view, it is feasible to investigate detailed texting records with the cooperation of telecommunication companies.

5.1.3 External Distractions

The results suggest that drivers who were distracted by external objects tend to be involved more in rear-end crashes. This effect is consistent across the age groups investigated (i.e., young and mid-age). External distractions induce less effective visual scanning patterns (Beijer, Smiley, & Eizenman, 2007) and the higher odds of rear-end crashes might be due to the direction of visual attention away from the lead vehicles leading to a degradation in response times and the maintenance of safe following distances (Neyens & Boyle, 2007).

After controlling for the effects of crash types, external distraction appears to decrease injury severities for young and old driver crashes; whereas no effect was observed for mid-age driver crashes. As shown in Figure 1, external distraction effects on injury severities are in the opposite direction compared to distraction sources inside of the vehicle, e.g., passenger, cell phone, and in-vehicle devices. Drivers who are distracted by external objects outside of the vehicle can still pick up roadway information on their periphery as opposed to drivers who are visually distracted by in-vehicle sources. However, it is surprising to see that conversing with passengers or on a call phone was more detrimental than external distractions. There are various potential explanations for this observed effect. Conversations may be more taxing on drivers' information processing channels by consuming working memory and prolonging drivers' TTC judgment. It is also possible that drivers may be exhibiting compensatory behaviours (e.g., reduced speeds) while looking at external objects. Further research is needed in this area to identify the underlying reasons.

5.1.4 Inattention

This study revealed that occupants of a crash which involves an inattentive driver often have less severe injuries; and inattentive drivers are most likely to be involved in rear-end crashes. Further, it is shown in Study One that rear-end crashes are often less severe. It should be noted that even after controlling for this effect, inattention still results in less severe injuries. This trend has also been reported in other studies. Liu and Donmez (2011) found that both police and civilian drivers, who were inattentive, were involved in less severe crashes. Neyens and Boyle (2008) confirmed this result for teenage drivers. These findings are somewhat counter-intuitive, because laboratory experiments suggest that inattention degrades visual scanning performance with decreased useful-field-of-views, longer eye fixations, and less frequent saccades (Harbluk, Noy, Trbovich, & Eizenman, 2007; Recarte & Nunes, 2000). However, previous research shows that cognitive workload results in reduced speeds, which might be one compensatory behaviour impacting crash severities (Lavalliere, et al., 2011). Apart from potentially lowered speeds of inattentive drivers, their performance could also be compensated by shorter TTC judgments.

It should be noted that it is quite hard to induce or manipulate inattention in a controlled manner. For example, in Harbluk et al. (2007), participants were required to perform arithmetic calculations, which likely is not representative of , for example, being “lost in thought”. Further research is required to understand the nature and effects of inattention as defined in crash reports.

5.1.5 Drowsiness

Although drowsiness does not involve secondary activities, it is also a significant human factor which impairs driving capability (Eoh, Chung, & Kim, 2005) and results in a progressive withdrawal of attention from the roadway. After controlling for crash type and other variables, Study One indicates that drowsiness increases the odds of severe injuries. Results show that drowsiness is detrimental for drivers in all age groups, but young and mid-age drivers seem to handle it better than old drivers. The results of Study Two suggest that drowsiness is associated with very high singular crash rates. Otmani et al. (2005) conducted a driving simulator study and confirmed that driving alone on the road is highly monotonous and drivers feel bored and tired. Low traffic might also contribute directly to the occurrence of a singular crash, as the chance of hitting another vehicle decreases when traffic is low.   Overall, compared to other distraction types, drowsiness has more dramatic effects on crash injury severities. Although it appears that the attention of the research community has recently shifted towards technology induced distractions, drowsiness still remains to be a large problem requiring novel mitigation solutions.

5.2 Research Method Limitations

Study One and Study Two are subject to a number of limitations. The variables utilized in these statistical models did not go through a robust selection process. These variables were selected based on previous studies, in which robust parameter selection processes were absent as well (Ghazizadeh & Boyle, 2009; Kockelman & Kweon, 2002; Liu & Donmez, 2011; McEvoy, 2007; Neyens & Boyle, 2007, 2008). A simple but ideal backward selection process should begin with all possible variables in the model, which may affect the dependent variable. However, this method cannot be effectively implemented in this particular study, given that the large amount of data results in statistically significant covariates, including those apparently correlated pairs. As a result, ad-hoc models were built to include variables that are considered to play a role in motor vehicle crashes based on current state-of-knowledge and the wide-spread consistency among previous crash data analysis. Still, we cannot say that there are no redundant or missing variables in these models.

A limitation of the models built in this thesis is the inability to identify the at-fault driver. Constrained by the limited amount of information that GES provides, i.e., at-fault drivers not identified, we are only able to assess the associations between distractions and crash outcomes. In order to move a step further to assess crash causations, the “at-fault driver” information is needed.

A general limitation with the use of crash databases is that these data are based on police reports and may present a biased sample (Gordon, 2009). For example, driver distraction might be underreported, especially if there are fatalities. Such a bias might have impacted the results of this thesis, likely generating more conservative estimates for the effects of distractions. This underreporting issue had been acknowledged previously, and several states are making efforts to collect better data on driver distraction (Sundeen, Accessed July 31, 2010).

It is, in general, difficult to study the effects of aging. While many factors (such as distraction and traffic complexity) can be manipulated in controlled settings, a person's chronological age cannot be manipulated. Inherent in the cross-sectional nature of this study is the fact that there are confounds in comparing the abilities of different age groups. For example, older drivers in general have more experience. Since longitudinal studies of age and driving are expensive and time-consuming, the differences observed in cross-sectional studies cannot be attributed to a specific factor such as degradation in cognitive abilities (Mather, 2007).

The quality of GES data is also a concern. For example, although GES includes a category of "talking to a passenger", data reported at the state level for some states (e.g., Missouri) do not include this information. On the other hand, the only geographic information reported in GES is the "region of a crash", i.e., mid-west, northeast, etc. This specification made it impossible for us to verify the quality of the data. However, at the national level, GES is regarded to be the best data source available. Fatality Analysis Reporting System (FARS) only includes fatal crashes, and Crashworthiness Data System (CDS) has an emphasis on severe crashes with detailed information on towed vehicles, overlooking minor crashes.

Chapter 6
Conclusions

6.1 Contributions to the Field

This thesis provides an exploratory study rather than an investigative one. The main contribution of this thesis is the identification of associations between different distraction types, age groups, and crash outcomes. Underlying reasons for the findings cannot be assessed. However, the findings provide the big picture and highlight areas that need further research and should be prioritized for policy making. For example, dialling/texting on cell phones should be tightly controlled since this distraction type is associated with the highest odds of severe injuries. This result provides additional support for banning of the use of hand-held phones.

The results of this thesis showed that drowsiness drastically increases the odds of severe injuries; this effect is most pronounced when the drowsy driver is mid-age or old. Further, drowsiness increases the odds of singular crashes. Previous research shows that singular crashes have higher odds of occurrence on low-traffic rural roads (Otmani, et al., 2005) and Study One revealed that crashes on rural roads are more severe. Thus, it is necessary to implement mitigation strategies that can keep drivers free from drowsiness. Attention should be given to rural driving and all age groups; although mid-age and old drivers appear to require even further attention. Potential strategies should be making the driving experience less monotonous and thus keep the drivers alert but without distracting them.

On the other hand, rear-end crash odds was shown to increase with urban driving . Moreover, external distractions, which might be more likely in an urban setting (e.g., billboard signs, more elements in the scenery), were also shown to increase the odds of rear-end crashes.

Appropriate measures can be taken to minimize externally distracting stimuli or the drivers can be provided with headway information or rear-end collision warning systems adaptive based on eye tracking.

As presented in Table 1, inattention accounts for 71% of driver distractions associated with a crash. Although inattention constitutes a large proportion in GES, it is not necessary to combat this problem from the crash injury severity perspective as inattentive drivers were often found to be in less severe crashes. Nevertheless, inattention still appears to be a significant issue based on the sheer number of crashes involving inattention. However, it is hard to assess inattention even in controlled settings (e.g., by detecting a reduced horizontal visual scanning pattern), which makes the quality of inattention reporting in crash records highly questionable. Naturalistic studies, such as Strategic Highway Research Program 2 (SHRP2 - currently underway), will provide further insights into the magnitude of this issue. Although there is plenty of research on passenger distractions, the majority of research efforts are on younger drivers. This thesis revealed that passenger distractions are more detrimental to older drivers as evidenced by the increase in odds of severe injuries. Thus, future research should also consider this group of drivers.

6.2 Future Research

To better understand the underlying reasons for different crash types, there is a need to identify the relations between driving performance, behaviour, and crash outcomes. Almost all performance and behaviour research is conducted in controlled settings, thus little is known about why certain types of outcomes are observed for different distraction types and age groups. For example, although close following distances have been suggested to increase the likelihood of rear-end crashes, there has not been any studies explicitly proving this hypothesis. The effect size on following distances for different types of distractions is also not clear. Following distances adopted under different types of distractions combined with response time degradations would have a joint effect on the likelihood of rear-end crashes as well as crash injury severities. This thesis tried to identify links between crash data analysis and controlled experiments on behaviour and performance. However, the many holes in the current state of knowledge in driving research made it impossible for the author to make concrete connections. Hence the discussions on potential causal factors were speculative at best. Current and future naturalistic studies, such as SHRP2, should create more explicit ties between performance, behaviour, and crash outcomes.

Another fundamental question to ask is: what are the tasks that drivers perform when they drive? Controlled studies impose the level of task demands raising concern about whether their results are representative of real-world driving, hence crash outcomes observed in the real world. The types of tasks that the drivers perform when they drive also have implications for distraction mitigation design. According to the Multiple Resource Theory (Wickens, 2008), some tasks are easier to perform concurrently (e.g., driving and listening to the radio). How the driver modulates their distracting activities during driving is not well understood and should be studied.

A general limitation of police reported crashes is that the crash reports only capture a fraction of the total exposure of distractions (see Figure 10). For example, if the drivers never run into a crash when they are distracted or they do not disclose their distracting activities in a crash report (or if they die during the crash), their status with regards to distraction will not be reported. An earlier study in Toronto dealt with this issue by collecting detailed cell phone usage data for property damage only crashes (Redelmeier & Tibshirani, 1997). This study collected crash reports for 14 months and checked the corresponding phone records during pre-crash moments. Such a semi-naturalistic data collection process is lengthy and costly. Thus, accession of cell phone records is rarely seen, although it should be the preferred way. Further, we still do not have a reliable way to get information for other distraction types at pre-crash moments (e.g., inattention) that do not involve the use of technology by the driver which creates an accessible record.

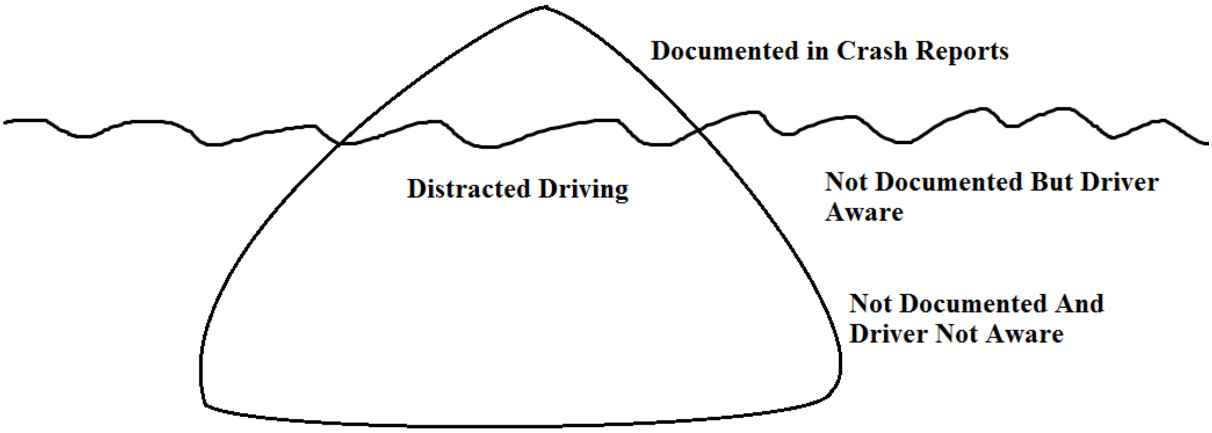

Figure 10: Documented and un-documented driver distractions (from Stutts et al. 2005 B)

References

Abdel-Aty, M. (2003). Investigation the relationship between celllular phone use and traffic safety. *Institute of Transporttion Engineers Journal, 73*(10), 38-42.

Amado, S., & Ulupinar, P. (2005). The effects of conversation on attention and peripheral detection: is talking with a passenger and talking on the cell phone different? *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(6), 383-395.

Baker, S., & Spina, K. (2007). Drivers' attitudes, awareness and knowledge about driver distractions: research from two central sydney communities. In I. J. Faulks, Regan, M., Stevenson, M., Brown, J., Porter, A., and Irwin J. D. (Ed.), *Distracted Driving* (pp. 255-268). Sydney, NSW: Australasian College of Road Safety.

Bao, Y., Kiss, M., & Wittmann, M. (2002). Effects of age and memory grouping on simulated car driving. *In Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp. 1853-1857). Santa Monica, CA.

Beijer, D., Smiley, A., & Eizenman, M. (2007). Observed driver glance behavior at roadside advertising signs *Transportation Research Record, 1899*, 96-103.

Beirness, D. J., Simpson, H. M., and Desmond, K. (2002). The Road Safety Monitor 2002: Risky Driving. Traffic Injury Research Foundation. Ottawa, Canada.

Boyce, T. E., & Geller, E. S. (2002). An instrumented vehicle assessment of problem behavior and driving style: do younger males really take more risks? *Accident Analysis & Prevention, 34*(1), 51-64.

Brookhuis, K. A., de Vries, G., & de Waard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis & Prevention, 23*(4), 309-316.

Chaparro, A., & Alton, J. (2000). Age related differences in driving performance and target identification. *In Proceedings of the IEA 2000/HFES 2000 Congress* (Vol. 4, pp. 56-59). San Diego, CA.

Cooper, P. J., & Zheng, Y. (2002). Turning gap acceptance decision-making: the impact of driver distraction. *Journal of Safety Research, 33*(3), 321-335.

de Ridder, S. N., Elieff, C., Diesch, A., Gershenson, C., & Pick, H. L. (2002). Staying oriented while driving. *In Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp. 206-208). Santa Monica, CA.

DeLucia, P. R., Kaiser, M. K., Bush, J. M., Meyer, L. E., & Sweet, B. T. (2003). Information integration in judgements of time to contact. *Quarterly Journal of Experimental Psychology, 56A*(7), 1165-1189.

Dinges, D. F. (1995). An overview of sleepiness and accidents. *Journal of Sleep Research, 4*(S2), 4-14.

Dingus, T. A., Klauer, S. G., Neale, V. L., Peterson, A., Lee, S. E., Sudweeks, J., et al. (2006). The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment. DTNH22-00-C-07007. U.S. Department of Transportation NHTSA.

Doherty, S. T., Andrey, J. C., and MacGregor, C. (1998). The situational risks of young drivers: the influence of passengers, time of day and day of week on accident rates. *Accident Analysis & Prevention, 30*(1), 45-52.

Donmez, B., Boyle, L. N., & Lee, J. D. (2006). The impact of distraction mitigation strategies on driving performance. *Human Factors, 48*(4), 785-804.

Drews, F. A., Pasupathi, M., & Strayer, D. L. (2008). Passenger and cell phone conversations in simulated driving. *Journal of Experimental Psychology: Applied, 14*(4), 293-400.

Eluru, N., & Bhat, C. R. (2007). A joint econometric analysis of seat belt use and crash-related injury severity. *Accident Analysis & Prevention, 39*(5), 1037-1049.

Eoh, H. J., Chung, M. K., & Kim, S.-H. (2005). Electroencephalographic study of drowsiness in simulated driving with sleep deprivation. *International Journal of Industrial Ergonomics, 35*(4), 307-320.

Farmer, C. M., Braver, E. R., & Mitter, E. L. (1997). Two-vehicle side impact crashes: The relationship of vehicle and crash characteristics to injury severity. *Accident Analysis & Prevention, 29*(3), 399-406.

Ghazizadeh, M., & Boyle, L. N. (2009). Influence of driver distractions on the likelihood of rear-end, angular, and single-vehicle crashes in Missouri. *Transportation Research Record, 2138*, 1-5.

Gordon, C. P. (2009). Crash Studies of Driver Distraction. In M. A. Regan, Lee, J. D., and Young, K. L. (Ed.), *Driver Distraction: Theory, Effects and Mitigation*: CRC Press, Florida.

Green, P., Hoekstra, E., & Williams, M. (1993). Further On-the-Road Tests of Driver Interfaces: Examination of a Route Guidance System and Car Phone. DTFH61-89-C-0004. U.S. Department of Transportation, Federal Highway Administration.

Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: impacts on drivers' visual behaviour and braking performance. *Accident Analysis & Prevention, 39*(2), 372-379.

Harrison, W. A. (1997). The limited potential of training for learner drivers: a view from the psychologists' lab. *In Proceedings of Safety in Action Conference*. Melbourne, Australia.

Heino, A., Van der Molen, H. H., & Wilde, G. J. S. (1996). Differences in risk experience between sensation avoiders and sensation seekers. *Personality and Individual Differences, 20*(1), 71-79.

Horberry, T., Anderson, J. R., Regan, M. A., Triggs, T. J., & Brown, J. (2006). Driver distraction: the effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention, 38*(1), 185-191.

Horrey, W. J., Lesch, M. F., & Garabet, A. (2008). Assessing the awareness of performance decrements in distracted drivers. *Accident Analysis & Prevention, 40*(2), 675-682.

Hosking, S. G., Young, K. L., & Regan, M. A. (2009). The effects of text messaging on young drivers. *Human Factors, 51*(4), 582-592.

Huelke, D. F., & Compton, C. P. (1995). The effects of seat belts on injury severity of front and rear seat occupants in the same frontal crash. *Accident Analysis & Prevention, 27*(6), 835-838.

Ingre, M., Akerstedt, T., Peters, B., Anund, A., & Kecklund, G. (2006). Subjective sleepiness, simulated driving performance and blink duration: examining individual differences. *Journal of Sleep Research, 15*(1), 47-53.

Kim, K., Nitz, L., Richardson, J., & Li, L. (1995). Personal and behavioral predictors of automobile crash and injury severity. *Accident Analysis & Prevention, 27*(4), 469-481.

Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J. D., & Ramsey, D. J. (2006). The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data. DO HS 810594. U.S. Department of Transportation NHTSA.

Kloeden, C. N., Ponte, G., and McLean, A. J. (2001). Travelling Speed and the Risk of Crash Involvement on Rural Roads. CR 204. Australian Transport Safety Bureau.

Kockelman, K. M., & Kweon, Y. J. (2002). Driver injury severity: an application of ordered probit models. *Accident Analysis & Prevention, 34*(3), 313-321.

Laberge, J., Scialfa, C., White, C., & Caird, J. (2004). Effects of passenger and cellular phone conversations on driver distraction *Transportation Research Record, 1899*, 109-116.

Lavalliere, M., Donmez, B., Reimer, B., Mehler, B., Couglin, J. F., Klauber, K., et al. (2011). A field study assessing lane changing and lane choice across age and multiple levels of cognitive demand. *In Proceedings of the Transportation Research Board 90th Annual Meeting*. Washington, D.C.

Lee, J. D., Young, K. L., & Regan, M. A. (2009). Defining driver distraction. In M. A. Regan, Lee, J. D., and Young, K. L. (Ed.), *Driver Distraction: Theory, Effects and Mitigation* (pp. 31-40): CRC Press, Florida.

Lenguerrand, E., Martin, J., & Laumon, B. (2006). Modelling the hierarchical structure of road crash data—application to severity analysis. *Accident Analysis & Prevention, 38*(1), 43-53.

Lesch, M. F., & Hancock, P. A. (2004). Driving performance during concurrent cell-phone use: are drivers aware of their performance decrements? *Accident Analysis & Prevention, 36*(3), 471-480.

Leung, S., & Starmer, G. (2005). Gap acceptance and risk-taking by young and mature drivers, both sober and alcohol-intoxicated, in a simulated driving task. *Accident Analysis & Prevention, 37*(6), 1056-1065.

Liu, Z., & Donmez, B. (2011). Effects of distraction on injury severity in police-involved crashes. *In Proceedings of the Transportation Research Board 90th Annual Meeting*. Washington, D.C.

Margolis, K. L., Kerani, R. P., McGovern, P., Songer, T., Cauley, J. A., Ensrud, K. E., et al. (2002). Risk factors for motor vehicle crashes in older women. *Journal of Gerontology. Series A, Biological Sciences and Medical Sciences, 57*(3), 186-191.

Massie, D. L., Campbell, K. L., & Williams, A. F. (1995). Traffic accident involvement rates by driver age and gender. *Accident Analysis & Prevention, 27*(1), 73-87.

Mather, R. D. (2007). Age and driving behaviour: contributions from human factors. *Journal of Scientific Psychology*, 24-31.

McEvoy, S. P., Stevenson, M. R., McCartt, A. T., Woodward, M., Haworth, C., Palamara, P., et al. (2005). Role of mobile phones in motor vehicle crashes resulting in hospital attendance: a case-crossover study. *British Medical Journal, 331*(7514), 428-430.

McEvoy, S. P., Stevenson, M. R., and Woodward, M. (2007). The prefalence of, and factors associated with, serious crashes involving a distracting activity. *Accident Analysis & Prevention, 39*(3), 475-482.

McGwin, G., Sims, R. V., Pulley, L., & Roseman, J. M. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: a population-based case-control study. *American Journal of Epidemiology, 152*(5), 424-431.

Mourant, R. R., & Rockwell, T. H. (1972). Strategies of visual search by novice and experienced drivers. *Human Factors, 14*(4), 325-335.

Muelleman, R. L., Wadman, M. C., Tran, T. P., Ullrich, F., & Anderson, J. R. (2007). Rural motor vehicle crash risk of death is higher after controlling for injury severity. *Journal of Trauma, 62*(1), 221-225.

Neyens, D. M., & Boyle, L. N. (2007). The effect of distractions on the crash types of teenage drivers. *Accident Analysis & Prevention, 39*(1), 206-212.

Neyens, D. M., & Boyle, L. N. (2008). The influence of driver distraction on the severity of injuries sustained by teenage drivers and their passengers. *Accident Analysis & Prevention, 40*(1), 254-259.

NHTSA. (2011). Traffic Safety Facts: Drowsy Driving. DOT HS 811 449. U.S. Department of Transportation NHTSA.

Nunes, L. M., & Recarte, M. A. (2002). Cognitive demands of hands-free-phone conversation while driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 5*(2), 133-144.

Otmani, S., Roge, J., & Muzet, A. (2005). Sleepiness in profesional drivers: effect of age and time of day. *Accident Analysis & Prevention, 37*(5), 930-937.

Otte, D., Sferco, R., Schafer, R., Eis, V., Thomas, P., & Welsh, R. (2009). Assessment of injury severity of newrside occupants in pole impacts to side of passenger cars in European traffic accidents - analysis of German and UK in-depth data. *In Proceedings of the 21th Intarnational Technical Conference on Enhanced Safety of Vehicles*. Stuttgart, Germany.

Owsley, C., & McGwin Jr, G. (2010). Vision and driving. *Vision Research, 50*(23), 2348-2361.

Pack, A. I., Pack, A. M., Rodgman, E., Cucchiara, A., Dinges, D. F., & Schwab, C. W. (1995). Characteristics of crashes attributed to the driver having fallen asleep. *Accident Analysis & Prevention, 27*(6), 769-775.

Poole, A., & Ball, L. J. (2005). Eye Tracking in Human-Computer Interaction and Usability Research: Current Status and Future Prospects. In C. Ghaoui (Ed.), *Encyclopedia of Human-Computer Interaction*. Pennsylvania: Idea Group, Inc.

Ranney, T. (2008). Driver Distraction: A Review of the Current State-of-Knowledge. DOT HS 810 787. U.S. Department of Transportation NHTSA Vehicle Research and Test Center.

Ranney, T., Mazzae, E., Garrott, R., & Goodman, M. (2001). NHTSA driver distraction research: past, present, and future. *In Proceedings of the 17th International Technical Conference on Enhanced Safety of Vehicles*. Amsterdam, Netherland.

Reason, J. T. (1990). *Human Error*. Cambridge, England: Cambridge University Press.

Recarte, M. A., & Nunes, L. M. (2000). Effects of verbal and spatial-imagery tasks on eye fixations while driving. *Journal of Experimental Psychology: Applied, 6*(1), 31-43.

Recarte, M. A., & Nunes, L. M. (2003). Mental workload while driving: effects on visual search, discrimination, and decision making. *Journal of Experimental Psychology: Applied, 9*(2), 119-137.

Redelmeier, D. A., & Tibshirani, R. J. (1997). Association between cellular-telephone calls and motor vehicle crashes. *New England Journal of Medicine, 336*(7), 453-458.

Reed, M. P., & Green, P. A. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *Ergonomics, 42*(8), 1015-1037.

Regan, M. A., Lee, J. D., & Young, K. L. (2008). *Driver Distraction: Theory, Effects and Mitigation*. Boca Raton, FL: CRC Press.

Rice, T., Peek-Asa, C., & Kraus, J. (2003). Nighttime driving, passenger transport, and injury crash rates of young drivers. *Injury Prevention, 9*(3), 245-250.

Ryan, G. A., Legge, M., & Rosman, D. (1998). Age related changes in drivers' crash risk and crash type. *Accident Analysis & Prevention, 30*(3), 379-387.

Starnes, M. (2006). Large-Truck Crash Causation Study: An Initial Overview. DOT HS 810 646. U.S. Department of Transportation NHTSA National Center for Statistics and Analysis.

Stokes, M. E., Davis, C. S., & Koch, G. G. (2000). *Categorical Data Analysis with the SAS System* (2nd ed.). Cary, NC: SAS Institute Inc.

Strayer, D. L., & Drews, F. A. (2004). Profiles in driver distraction: effects of cell phone conversations on younger and older drivers. *Human Factors, 46*(4), 640-649.

Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science, 12*(6), 462-466.

Stutts, J. C., Feaganes, J., Reinfurt, D. W., Rodgman, E. A., Hamlett, C., Gish, K., et al. (2005). Drivers' Exposure to Distractions in Their Natural Driving Environment. *Accident Analysis & Prevention, 37*(6), 1093-1101.

Stutts, J. C., Knipling, R. R., Pfefer, R., Neuman, T. R., Slack, K. L., & Hardy, K. K. (2005 B). A guide for reducing crashes involving drowsy and distracted drivers. *In Vol. 14 of the NCHRP Report 500: Guidance for Implementation of the AASHO Strategic Highway Safety Plan*. National Cooperative Highway Research Program.

Stutts, J. C., Reinfurt, D. W., Staplin, L., & Rodgman, E. A. (2001). The Role of Driver Distraction in Traffic Crashes. AAA Foundation of Traffic Safety. Washington, D.C.

Sundeen, M. (Accessed July 31, 2010). Cell Phones and Highway Safety: 2006 State Legislative Update. http://www.ncsl.org/default.aspx?tabid=18374.

Sussman, E. D., Bishop, H., Madnick, B., & Walter, R. (1985). Driver inattention and highway safety. *Transportation Research Record, 1047*, 40-48.

Treat, J. R., Tumbas, N. S., McDonald, S. T., Shinar, D., Hume, R. D., Mayer, R. E., et al. (1979). Tri-Level Study of the Causes of Traffic Accidents. DOT HS 805 099. U.S. Department of Transportation, NHTSA.

Wang, J., Knipling, R. R., & Goodman, M. J. (1996). The role of driver inattention in crashes: new statistics from the 1995 crashworthiness data system. *In the 40th Annual*

Proceedings of Association for the Advancement of Automotive Medicine. Vancouver, British Columbia, Canada.

Wasielewski, P. (1984). Speed as a measure of driver risk: observed speeds versus driver and vehicle characteristics. *Accident Analysis & Prevention, 16*(2), 89-103.

Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors, 50*(3), 449-455.

Williamson, A. (2009). The relationship between driver fatigue and driver distraction. In M. A. Regan, J. D. Lee & K. L. Young (Eds.), *Driver Distraction: Theory, Effects, and Mitigation* (pp. 383-392): CRC Press.

Xie, Y., Zhang, Y., and Liang, F. (2009). Crash injury severity analysis using Bayesian ordered probit models. *Journal of Transportation Engineering, 135*(1), 18-25.

Young, M. S., & Mahfoud, J. M. (2007). Driven to Distraction: Determining the Effects of Roadside Advertising on Driver Attention. The Rees Jeffreys Road Fund.

Young, M. S., Mahfoud, J. M., Walker, G. H., Jenkins, D. P., & Stanton, N. A. (2008). Crash dieting: the effects of eating and drinking on driving performance. *Accident Analysis & Prevention, 40*(1), 142-148.

Zhu, X., & Srinivasan, S. (2011). A comprehensive analysis of factors influencing the injury severity of large-truck crashes. *Accident Analysis & Prevention, 43*(1), 49-57.