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Determining the cause of motor-vehicle related paediatric bicycling injuries

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by

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Abstract

Despite health benefits, bicycling as a form of active transportation has declined. Bicycle-motor vehicle collisions (BMVCs) pose a risk for severe injury to youth and are a leading deterrent to youth bicycling. This thesis aims to identify characteristics of BMVCs. Divided roads with no barrier, signage presence and peak traffic times had lower odds of severe injury in youth after BMVC. We adapted a culpability tool to Alberta police collision report data and used this tool to define a control group of drivers from collisions involving only motor vehicles. These controls were compared with drivers in BMVCs. Drivers older than 54 years had higher odds of youth BMVC, light trucks/vans had lower odds and driving between18:01hrs-24:00hrs had the highest odds of BMVC. It is possible to adapt culpability tools to other jurisdictions and can be used to address the often-neglected role of the driver in youth BMVCs.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
AB	Alberta
aOR	Adjusted Odds Ratio
AT	Active Transportation
BMVC	Bicycle-Motor Vehicle Collision
CART	Classification and Regression Trees
CCST	Canadian Culpability Scoring Tool
CI	Confidence Interval
ED	Emergency Department
ISS	Injury Severity Score
MV	Motor Vehicle
MVC	Motor Vehicle Collision
OR	Odds Ratio
PA	Physical Activity
QIE	Quasi-Induced Exposure
VKT	Vehicle Kilometers Travelled

CHAPTER 1: INTRODUCTION

1.1 Background

Unintentional injury is the leading cause of death in individuals under 44 years of age in Canada (1). The most frequent specific cause of these injuries, approximately 41%, are traffic related (i.e. Motor-vehicle (MV) use, bicycling, walking) (2). On a global scale, traffic injuries create costs equivalent of approximately 3% of each country's GDP and are responsible for 1.25 million deaths annually, with vulnerable road users (i.e. bicyclists and pedestrians) accounting for about half of these fatalities (3). The social and economic cost of these preventable injuries has led to several calls from the United Nations and The World Health Organization through their "Decade of Action for Road Safety 2011–2020" and "Sustainable Development Goals" to reduce traffic fatalities 50% by 2020(3).

International campaigns such as VisionZero and National organizations including the Canadian Paediatric Society and Parachute have also taken positions to address the risk of traffic injury in youth, especially in vulnerable groups such as bicyclists (4-7). Approximately 12 million Canadians cycle each year (8), with those in the youngest age groups having the highest participation rates (e.g. 86% of 12-15 year olds) (8). Bicycling offers environmental, physical and mental health benefits (9); however, bicycling continues to be a leading cause of sports and recreation related injury in youth (10). Efforts to reduce injuries in youth cyclists are imperative for this vulnerable segment of society to enjoy the benefits of bicycling without undue risk.

1.1.1 Bicycling and Active Transportation in Public Health

In an era of highly prevalent childhood obesity (11) and increasing rates of type II diabetes in youth (12), it is important to consider and promote forms of physical activity (PA) that are cost-effective, easily accessible and easily integrated into daily life. Bicycling not only has lower private and social costs (compared with MV transport) (13), but active transportation (AT) also improves overall PA levels (14, 15). As well, bicycling as a form of active commuting has been associated with lower incidence of cardiovascular disease, cancer and all-cause mortality (16). Bicycling is an accessible form of AT with 91% of children aged 5-12 and 77% of adolescents (13-17 years old) bicycling at least once a year in Canada (17). Active school transportation offers the opportunity for regular PA. Bicycling in particular may provide a number of specific physical health benefits including improved cardiorespiratory fitness and reduced all-cause mortality, with these benefits seen in a dose-response relationship (18, 19). Adolescents who use bicycling as a form of AT to school have shown higher aerobic power, isometric muscular endurance, dynamic abdominal muscular endurance and flexibility compared with adolescents who walk or use passive travel to school (20). Despite the benefits, only one third of Canadian children report using AT to get to school (21), while use of inactive forms of transport (e.g., driving or being driven) has increased (22).

Being driven to school throughout childhood may impede the ability of youth to develop independent mobility (23). Independent mobility may provide youth with benefits such as improved autonomy, self-determination and confidence (24, 25). Beyond the individual level risks, dependence on vehicles for school travel leads to increased traffic congestion around schools, promoting risky drop-off behaviours that increase risk of MV collision with vulnerable road users (26). Bicycling can also be an effective method to reduce pollution through carbon emissions, thereby improving air quality at a societal level (27). There is also evidence that bicycling may contribute to local economies as cyclists visit street-level businesses more often than MV users (28).

On a population level, slight increases in bicycling uptake could have important public health implications in terms of reduction in MV dependence, improvement in PA levels, physical fitness, social benefits and improvements in mental health. Understanding and addressing the major deterrents to bicycling is imperative in promoting healthy behaviour.

1.1.2 Bicycling Risks and Injury Burden

While bicycling provides a number of benefits, there are also risks. It is important to understand these potential risks and weigh those against the potential benefits.

While bicycling is likely to reduce overall levels of pollution, cyclists themselves may be at risk of health risks associated with pollution. Bicyclists riding on the road are at a height and position relative to MV exhaust that results in the inhalation of black carbon, nitrogen dioxide, particulate matter, ultra-fine particulate matter and carbon monoxide (29). While the long-term effects of bicycling on or near roads is not well-established, living within 200m of highways may increase the risk of asthma and reduce lung function in youth (30). Therefore, the possibility of lung disease due to repeated exposure to traffic related pollutants in cyclists is a real concern. However, by adopting the use of separated cycle paths the exposure may be reduced significantly (29).

Safety concerns around traffic exposure are commonly cited, by both parents and youth, as a leading deterrent to school transport bicycling (31-33). Bicyclists represent approximately 1.5% of road users, but this small group accounts for 3.2% of all road traffic fatalities (34, 35). Youth cyclists could be at a higher risk of injury than adults since they may not have the situational awareness, cognitive or motor skills to safely ride bicycles in the current road structure (31, 36, 37). From 2015-2016 930 youth were hospitalized in Canada due to bicycling injuries, second only to playground injuries for the age group and representing approximately 15% of all sports-related youth hospitalizations in the country (38). Of these severe injuries, nearly two-thirds of children involved in BMVCs will require assistance with daily living activities 6 months post-collision compared with only 27% of children hospitalized in other sports (39).

This risk of injury may function in a vicious circle; since risk of injury is a major deterrent to bicycling, there is a decrease in total number of bicyclists. This decline contributes negatively to the safety in numbers principle that posits a potential injury rate reduction by increasing the number of road users engaging in AT (40).

1.1.3 Injury Prevention

The first step to understanding injury prevention is to understand what an injury is. Injury as a concept has been defined by The World Health Organization as “the physical damage that results when a human body is subjected to energy that exceeds the physiological tolerance or results in lack of one or more vital elements, such as oxygen" (41). This definition provides context for what injury is, but may not be easily applied to injury as a definition in research. To that end, researchers have defined injury in a number of ways, including time-loss from activity as well as physical symptoms (42). The variety of definitions can lead to issues in data collection, particularly in the case of questionnaires (43). Time-loss from activity as a definition allows injury data to be captured relatively easily and severity could be quantified using the number of matches or days missed. However, time-loss may be limited insofar as physical injury that may not always preclude an individual's ability to participate. In the context of AT, which may be necessary for some individuals to attend school or work, there could be further incentive for individuals to continue bicycling regardless of physical injury.

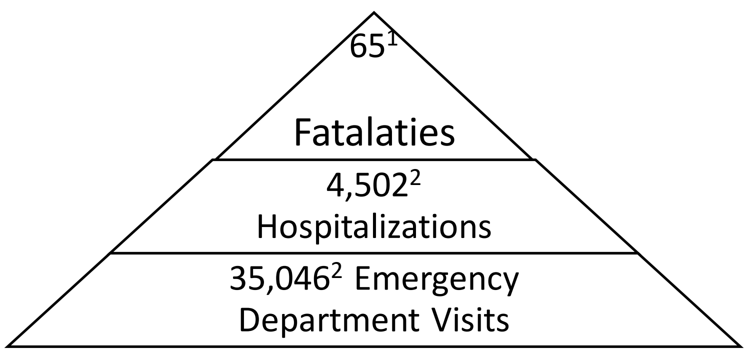

Figure 1. Example of an injury pyramid for bicyclist injuries in Canada

1: Statistics Canada. *Table 102-0540 - Deaths, by cause, Chapter XX: External causes of morbidity and mortality (V01 to Y89), age group and sex, Canada, annual (number),* CANSIM (database).

2: National Ambulatory Care Reporting System, 2015–2016, Canadian Institute for Health Information.

Injury severity can be quantified, roughly, by using time-loss, but can also be categorized using broad approaches such as the injury pyramid (44). Figure 1 illustrates an injury pyramid example as it relates to Canadian pedal cyclists. The injury pyramid, in this setting, consists of emergency department (ED) visits at the base, deaths at the tip and hospitalizations in the middle. The shape is meant to indicate smaller numbers as the severity of the injuries increase (45); though, this could be expanded to include "near misses" at an even wider base level.

Injury can also be scored using standard measures, for example, the injury severity score (ISS) ranges from 0-75 using the squared sum of the three most severe injuries from six groups of body regions (46). Both methods indicate that there can be a grade of injury while the ISS provides a more practical application, the injury pyramid visualizes the relationship between severe and non-severe injuries.

Just as injury itself can be categorized into varying levels, so too can injury prevention, where levels of injury prevention are typically separated into: primary (prevent the injury), secondary (reduce the severity of injury) and tertiary (care taken after injurious event to reduce the consequences) (47). The ultimate standard for injury prevention would be to attain primary prevention; however, until the actual mechanism of injury is understood then the injury may not be predicted and subsequently prevented.

The need to predict and prevent injuries has led to the generation of several etiologic injury models. For example, a 'dynamic model' has been proposed by Meeuwisse et al. (48) where injuries are understood as 'dynamic and cyclical'. That is, while an individual may have factors that predispose them to injury, they may not experience injury every time that they enter the playing field. The mechanism of injury may occur due to individual factors (internal) and/or environmental factors, but the existence of such factors may not guarantee injury. An important note is that the individual repeats participation and that after many events without injury they may finally be exposed to an inciting injury producing event. A key for understanding how to prevent injury is to understand the interplay between a possibly changing susceptibility of individuals, external factors and how those factors and susceptibility interact to produce injury during one event, but fail to produce the same injury in other events.

Consider the example of a youth who bicycles to school each day. Using the dynamic and cyclical model, the youth could be injured, uninjured or removed (fatal injury or decision to no longer bicycle) from the injury model, each trip, with the vast majority of trips being non-injurious. The youth may have a number of internal risk factors, for example being a young child (less developed motor and cognitive skills and less experience bicycling (37, 49)). These skills and experience will change each time they enter the environment (e.g., lack of sleep reduces cognitive skills and increases risk (50)). Conversely, each time they bicycle they will gain experience and improve motor skills potentially contributing to a reduced risk of injury on subsequent trips. The external factors in this example could include the use or removal of a helmet or traffic exposure (51). Vehicle exposure and action may change each time the youth enters the environment with some actions of vehicles increasing risk to the youth and some actions reducing risk. Helmets may reduce risk of severe head injury in the case of collision (52), but whether a helmet is fit or worn properly may change each time the child enters the bicycling environment thereby affecting risk of head injury (53). In applying the dynamic recursive model to this example, it is important to consider that each and every time the child enters the bicycling environment, internal and external factors will be different and that adaptations will be made in response. While the model was developed in the context of sports injuries, there is utility in using it to frame the complexities of youth BMVCs, to recognize the need to understand inciting and non-inciting events and to understand the interaction of individuals and the environment in these collisions.

Another example of an injury model is the 1972 work by Dr. William Haddon Jr., commonly referred to as Haddon's Matrix, that describes the relationship between those involved in injury producing events and the environments in which those events occur (54). We can understand from Haddon's 3x3 matrix that there are factors related to the 'host' (injured individual), the 'agent' (the source of energy) and the 'environment' (where the injury occurs) comprising the columns and three levels of temporality: pre-event, event and post-event comprising the rows. This matrix could include risk factors or, alternatively, could include prevention strategies related to those factors. An example of Haddon's matrix applied to youth BMVC is given in Table 1. Etiologic understanding of injury as proposed by Haddon includes holistic measures that can influence injury reduction; measures that not only protect the individual at the point of injury, but prevent the situation from ever occurring.

Table 1. Haddon's Matrix with example of youth BMVC

Time	**Host** (Youth Bicyclist)	**Agent** (Motor-vehicle)	**Environment** (Streetway)
Pre-Event	Defensive/Safe bicycling behaviour.	Driver training. Legislation to discourage risky behaviours (i.e. alcohol/drug consumption, distracted driving). Vehicle design to reduce blind spots.	Implementation of traffic calming measures. Environment that reduces potential conflict of bicycles and vehicles (i.e. physical separation or marked crossings)
Event	Safety equipment usage. Speed and road worthiness of bicycle.	Design of vehicle to reduce injury of bicyclists. Braking/speed control. Technologic functions (i.e. back-up camera).	Environment that is clear of debris or on/near road hazards.
Post-Event	Access to health services. Physical rehabilitation. Building confidence to bicycle again.		Unimpeded access for health services.

Despite this understanding of injury prevention as a holistic approach, policies have generally been aimed at primary prevention by educating individuals about safety, thereby attempting to influence behaviour. While youth bicycling education and skills programs have been implemented across Canada, a recent systematic review has indicated that these programs have been largely ineffective at reducing youth cyclist injury (55). However, some policies aimed at individuals have been effective at reducing injury severity in bicyclists. For example, helmets reduce the risk of head injury among cyclists of all ages (56), and bicycle helmet laws have been shown to be effective in increasing helmet use

(57). While helmet use policy has been effective in reducing injury severity in BMVCs, it is only one piece of the puzzle. This approach does not prevent the injury producing event from occurring and only reduces the risk of head and face injury. Furthermore, the injury prevention paradigms described dictate that environmental, driver and youth cyclist factors be considered in tandem and that events that do not result in injury be considered in conjunction with those that do. In understanding injury prevention through these models, we can see that there is a need to consider the complexities of BMVCs holistically in order to further reduce injury severity and prevalence in youth cyclists.

In the context of holistic approaches to reducing injury severity, factors related to the motorist (agent), the bicyclist (host) and the environments in which youth BMVCs occur must be considered. This could be achieved by considering what factors involved in these three areas are contributing to serious or severe injuries relative to those events that do not produce severe injury. Strategies to prevent youth BMVCs should also consider the agent, host and environment. While description of those involved could be readily available from police collision report data or health records, a comparison group representing the population from which youth BMVCs could occur can be more difficult to establish. An in-depth review of the literature surrounding youth bicyclist, motorist and environmental risk factors for BMVC follows in chapter 2; however, there is relatively little information on motorists involved in youth BMVCs. Police collision report data could be used to address this issue as it includes demographic information on both the motorist and youth bicyclist. This data source also provides the opportunity to leverage a traffic safety technique known as ‘culpability analysis’ to define a control group of drivers that will represent the typical driving population (58).

1.2 Thesis Outline

1.2.1 Thesis Aim

The aim of this thesis is to examine and identify risk factors for youth BMVCs in relation to the cyclist, motorist and environment involved. In understanding the risk factors, action can be taken to prevent collisions from occurring in the first place, thus creating a safe environment for youth to engage in active forms of transportation, including bicycling.

1.2.2 Thesis Objectives

Three distinct, yet related, objectives were identified that will address the overall aim of the thesis:

Objective i: To determine the environmental, driver and youth characteristics that contribute to severe injury in youth BMVCs.

Objective ii: To adapt and automate a Canadian culpability analysis tool to Alberta police traffic collision report data in order to identify drivers who represent the motorist source population.

Objective iii: To undertake a case-control study that will identify motorist and environmental characteristics that contribute to BMVCs.

1.2.3 Thesis Format

This thesis consists of six chapters. Chapter 1 provides the fundamental background of bicycling and injury prevention as it relates to the thesis objectives. Chapter 2 contains a review of the literature on risk factors for BMVCs as well as a brief history and explanation of the quasi-induced exposure method. The next three chapters consist of manuscripts that address objectives i, ii and iii, respectively: chapter 3 "Child and Adolescent Bicycling Injuries Involving Motor Vehicle Collisions", chapter 4 "Adaptation of a Canadian Culpability Scoring Tool to Alberta Police Traffic Collision Report Data" and chapter 5 "Identifying Motorist Risk Factors in youth Bicycle-Motor Vehicle Collisions". chapter 6 is the final chapter and discusses the findings of all three manuscripts, the strengths, limitations and implications of those findings as well as the future directions.

1.3 Ethics Approval and Data Sharing

This study was approved by the Conjoint Health Research Ethics Board at the University of Calgary (REB-16-0438). We have a data sharing agreement with Alberta Transportation that allows the use of an electronic database of Calgary and Edmonton police traffic collision report data from 2010-2014. This database maintains accuracy by being subjected to several computerized and manual inspections, annually. The electronic data reside in two locked and secure onsite (Alberta Children's Hospital) computers and one off-site storage unit. Only I, the primary investigator, three summer students and a post-doctoral fellow have been given access to these data. These data are anonymized; for example, names and contact information were removed prior to receiving the database.

Each collision is given a unique case number and each person involved is assigned a number within that collision (e.g., casenumber= 4567890, personnumber= 1/2/3/4 etc.) by the officer. University of Calgary standards dictate that, given this is a study with human subject involvement, but is not a clinical trial, we will retain the data 5 years after the close of study and the data received will be subsequently destroyed by the Archives at the University or the Privacy and Records Office in the Cumming School of Medicine.

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CHAPTER 2: LITERATURE REVIEW

2.1 Preamble

This chapter represents a review of the literature as it relates to the possible factors related to youth BMVCs as well as a background on key methodologies employed in later chapters. The review of this literature was done by using search engines for peer-reviewed literature (e.g., Medline, Google Scholar); For example, search headings in Medline included "Accidents, Traffic", "Bicycling" and "Child". As well, reference lists within articles were examined for possibly relevant information. This second chapter will examine possible youth risk factors for BMVCs and bicycling injury, the importance of driver characteristics in youth BMVCs, the role of the environment related to youth BMVCs and a brief summary and description of the quasi-induced exposure, and related, methodologies.

2.2 Youth Injury Risk Factors

Risk factors for injury must be identified in order to predict and prevent injuries from occurring. Age and sex are non-modifiable risk factors, but understanding the role of age and sex can help researchers understand the role these factors may play in confounding; as well, decision-makers can better target groups that may be at higher risk of injury. While age and sex are often considered in studies, there seems to be little consistency on the role of these two potential risk factors (1). It has been observed in some studies that age is a risk factor for bicycle related injuries, although the exact age group varies with the sample or data coding as well as the mechanism of injury. For example, Tin Tin et al. (2). and

Thompson et al. (3) identified the age group 5-14 with the highest risk of bicyclist injury; however, Tin Tin et al. did not observe an increased risk of BMVCs in that age group. A prospective cohort study (4) in France found that risk of bicycling injury was higher in some younger aged groups and that this relationship was different between males and females. Males 12-14 years of age and females 7-9 years of age demonstrated the highest risk of bicycling injury compared with all other ages (4).

BMVCs in Spain from 1993-2009 were examined and identified that being male and being an adolescent or young adult were risk factors for bicycling injury (5). As well, this study identified an increased risk of BMVCs in addition to the risk of overall bicycling injury for this younger age group. A Canadian study demonstrated slightly different results. They did not observe an age-dependent risk of collision requiring hospital admission in youth cyclists, but did identify higher odds of severe injury in males (6). Still, a number of other studies have not seen any age differences (6-9) or sex differences (8-11) with regard to bicycling injury risk.

Modifiable risk factors identified in the literature include wearing dark clothing with few reflectors, consuming drugs, non-utilitarian bicycling, low parental socioeconomic status or wearing a poor fitting helmet (1, 5, 12, 13). Helmet usage in particular has been observed in multiple case-control studies to reduce risk of severe injury in cyclists (14, 15).

Generally, some researchers have pointed to an inability to accurately and consistently identify exposure (e.g. vehicle kilometers travelled or number of trips) in cyclists as a potential issue in bicycling safety research (16, 17). That is, by not knowing exactly how much youth are exposed to bicycling (thereby exposed to bicycling injury risk), it can be difficult to ascertain to what degree factors are playing a role bicycling injury.

2.3 Studying Driver and Environmental Factors

Collisions that involve a MV are associated with severe injury in youth cyclists (6, 18). Despite the role of MVs in severe collisions, there is a relative paucity of research on driver characteristics when compared with research on youth cyclists.

The lack of research on drivers can contribute to reduced accountability of the driver and may fuel an overestimation of the fault of youth bicyclists involved in collisions with motor vehicles – a “negative halo” bias (19). A survey of police officers and motorists involved in youth pedestrian-motor vehicle collisions indicated that 75% of motorists apportioned blame to the youth pedestrian, while considering themselves at-fault in just 1.8% of incidents (20). Perhaps more surprisingly, the police officers surveyed found the pedestrian at fault 93.1% of the time and motorists at-fault only 5.4% (20). Another study in California used police reported fault on collision reports involving MVs and children under 15 years of age; they found that police considered drivers at-fault in approximately 25% of collisions, children at fault in approximately 53% of collisions with uncertainty in attribution of fault in approximately 22% (21). In the context of the possible negative halo bias, if youth are most often considered at fault by officers then this may lead to more officers making the assumption that the youth is at fault, almost implicitly, and without consideration of environmental or traffic factors surrounding the collision (22).

Some risk factors of drivers for collisions with youth cyclists that have been identified include being over 60 years of age, alcohol consumption and not using safety devices (i.e. seat belts) (5).

Generally, speed of the MV and the speed limit can influence severity of collision and crash risk in BMVCs. For example, roads with speed limits over 70km/h have increased risk of serious injury (7). Rural environments may increase the risk of head injuries in youth cyclists (11). Larger vehicles are thought to be at a higher risk of colliding with bicyclists due to larger blind spots and these may relate especially to collisions at intersections (23). Moreover, poor lighting conditions, intersection presence, poor or obstructed road conditions and lack of bicycle infrastructure have been shown to increase risk of more severe bicycling injuries (24-28). Reduced MV speeds through traffic calming measures may not only reduce risk of collision between bicyclists and MVs, but also reduce risk of collision with other bicyclists (29) and can potentially reduce injury severity in collisions involving both pedestrians and bicyclists (30).

It is also important to consider that youth are permitted to cycle on sidewalks and this may present unique challenges or solutions to traffic exposure and BMVC risk (25). It has been observed sidewalk bicycling can increase risk of injury/crash in all ages (primarily adult), with risk being 1.6 to 18 times higher on sidewalks than roads (31). If youth are unable to safely ride on roadways then they would be forced to bicycle on sidewalks if bicycling infrastructure does not exist. As well, since some youth bicycle for fun rather than for purpose (to work or school) they may be at a higher risk for collision and severe injury (6, 32).

Last, the so-called "safety in numbers" appears to reduce risk to vulnerable road users; meaning that with more cyclists using the road there should be a reduction in severe injuries (33). The volume of other road users may work similarly to high MV road volume, where simply having more vehicles on the road also reduces traffic speed and may make drivers more aware of their surroundings and potential for conflict. To that end, it has been observed that rush hour times (6:31–8:30 am and 4:01–6:00 pm) for MVs did not increase risk of severe injury in youth bicyclists relative to off-peak hours, despite the relative increase in traffic exposure (6).

2.4 Quasi-induced Exposure and Culpability Analysis

Collision data in traffic safety has sought to determine rates of collisions as a means to describe those who are most often involved in these incidents. The denominators for these rates are often based on survey data to estimate total distance travelled, through population estimates or through number of licensed drivers (34). However, survey data may be subject to response bias, and population/licensed drivers may be inaccurate since individuals on roadways may not necessarily have licenses and those with licenses may not necessarily drive. Furthermore, these designs are unable to capture risk factors that can change over time (i.e. cell phone use, drug use, fatigue).

The induced exposure (indirect measure of traffic exposure) method was first described in 1967 by Thorpe (35), and was developed with the intention to describe driving populations while addressing the limitations described above. Induced exposure posits that in each two-vehicle collision there is a driver who is at-fault and one that is not, and that the not-at-fault driver will be representative of the typical MV driver (34). However, the methodology of this initial induced exposure method was not fully developed and required a more systematic approach to responsibility assessment. These issues were generally addressed in 1972 by Haight (36) and was renamed "quasi-induced exposure" (QIE). QIE is reliant on several factors, notably, that there is always a driver at-fault, that the at-fault driver "randomly selects" the not-at-fault driver from all other road users (the "randomness assumption") (37) and that the assessment of fault is robust (38).

QIE assessment of fault originally used police assessment of fault; however, this method to consider fault may be subject to the "negative halo bias" (19). More objective assessments of fault use a standardized and validated tool that considers external and internal factors surrounding the collision to determine fault across a scale. One of the earliest fault analysis tools was used in Toronto, Canada in 1951 and considered fault on a scale of 0-10, with scores 8-10 being at-fault and 0-2 being not-at-fault (39). The scale of fault allows more leniency in how contributions from each driver is assessed rather than a binary assessment within "clean" (one driver at fault and one not-at-fault) two-vehicle collisions. Since 1951, the subsequent iterations of fault analysis tools have become more complex and consider multiple factors. For example, a widely used and validated fault-analysis tool was proposed by Robertson & Drummer in 1994, and considers eight categories (road conditions, vehicle conditions, driving conditions, type of collision, witness observations, law obedience, driving task and level of fatigue) scored from 1-4 in assessing contribution (40). By considering a multitude of contributory factors and by assessing these factors in a systematic and harsh way, culpability analysis tools offer the ability to better describe not-at-fault drivers who will be representative of the general driving population (38).

Since QIE was first described, the research using this approach has seen a relative spike, especially in recent years (37). Validation work was done to ensure the "randomness assumption"; to satisfy this assumption researchers have studied the distribution of demographic characteristics in those not-at-fault drivers. First, the characteristics of drivers causing the crash should differ significantly from those not-at-fault and those differences should represent known risk factors for causing collision (38). It has been described that more severe collisions are often the most complete in police report data, so this may give some guidance in better understanding a "ground-truth" population of not-at-fault drivers (37). With this understanding, it is reasonable to expect that a truly robust fault assessment will demonstrate the same characteristics of drivers across all levels of severity in collisions. Some validation work includes comparing demographic information from a QIE study to the expected demographics based on population-level survey data (total vehicle kilometers travelled) (41). Others have compared demographic information of drivers not-at-fault in two vehicle collisions against those in three vehicle collisions and found no difference in the characteristics of these groups (34, 42). The original understanding of QIE is that there must be two-vehicle collisions with one driver at-fault and one not-at-fault;

however, given the relative similarity of those not-at-fault in two and three vehicle collisions this definition could be expanded to all collisions. It has also been discussed that collisions where all vehicles are not-a-fault could be considered as well (33). Additionally, this approach has been applied to road users that are not MVs; Martinez-Ruiz et al. applied this methodology to bicyclists (all ages) in order to assess risk factors for collisions with MVs (43).

Overall, QIE with a robust assessment of fault potentially allows for an easily accessible and cost-effective measure of the characteristics of the driving source population. QIE and culpability analysis techniques have been used in traffic safety literature for decades, and have recently garnered attention from epidemiologists as a potential means to select controls in case-control studies (44). With this is mind, drivers involved in MV-MV collisions could be considered, using culpability analysis, to identify a control group of drivers who could be compared with motorists involved in youth BMVCs.

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CHAPTER 3: CHILD AND ADOLESCENT BICYCLING INJURIES INVOLVING MOTOR VEHICLE COLLISIONS

3.1 Preamble

This manuscript aims at identifying risk factors for youth cyclists who are hospitalized after BMVCs. The manuscript was prepared to be submitted to the journal *Injury Prevention* as a brief report, although there are some minor differences related to thesis formatting requirements. Preliminary work related to this manuscript was also accepted for oral presentations at the following conferences:

Pitt T**,** Piatkowski C, Farias M, Graff P, Owens L, Howard A, Nettel-Aguirre A, Rowe BH, Patel A, Hagel B. Child and adolescent bicycling injuries involving motor vehicle collisions. Canadian Association of Road Safety Professionals Conference, 2017. Toronto, Canada.

Pitt T**,** Piatkowski C, Farias M, Graff P, Owens L, Howard AW, Nettel-Aguirre A, Rowe BH, Patel A, Hagel BE. Risk Factors for Severe Motor Vehicle Related Paediatric Bicycling Injuries. Alberta Children's Hospital Research Institute Research Symposium, 2017. Calgary, Canada.

3.2 Abstract

Background: Bicycle-related injuries are among the most common injuries during recreational activities for children in Canada. Serious and fatal injuries can result from

BMVCs. Factors associated with these collisions need to be identified in order to develop effective primary prevention strategies.

Aims: To examine the environmental, motor-vehicle driver, and bicyclist characteristics of reported youth (<18 years) BMVCs resulting in severe and non-severe injuries.

Methods: Working with Alberta Transportation, the collision reports of every youth BMVC reported from 2010 to 2014 by Calgary and Edmonton Police Services in Alberta were identified. Police reports included environmental factors and characteristics of those involved in the collision. Classification trees as a means of variable selection were used to inform multivariable logistic regression modelling. This logistic regression was used to examine the differences in exposures between collisions resulting in minor/no injury (non-severe) and major/fatal injury (severe) in youth bicyclists.

Results: 423 youth BMVCs were identified, 380 non-severe and 43 severe. There were no statistically significant driver or bicyclist characteristics increasing or decreasing odds of severe injury to the youth bicyclist. The adjusted model for environmental characteristics included intersection status, peak time, driving conditions, road type and traffic control device presence. Lower odds of severe injury on divided roads with no barrier and during peak time were observed. These results remained when also adjusting for cyclist sex and age; as well, after including cyclist age and sex traffic signage reduced odds of severe collision.

Conclusion: Although some cyclist factors such as sex bordered statistical significance, only environmental characteristics were observed as statistically significant contributors to

severe injury to youth following BMVC.

3.3 Introduction

Bicycling has physiological and environmental benefits (1). However, bicycling is one of the leading causes of sport injury in Canadian youth (<18 years old) with over 900 youth hospitalized due to bicycling related injuries every year, second only to playground injuries (2). The risk of injury, particularly due to motor-vehicle collision, is a major deterrent for both parents and youth to bicycling (3). This risk may be greater for children and adolescents who have less developed cognitive ability, poorer situational awareness and worse hazard perception than adults (4, 5).

A recent systematic review of severe bicycling injury literature concluded that studies to date tend to focus on cyclists admitted to hospital or present in emergency departments (6). Data collection in these hospital settings focused on the youth cyclist and their behaviour, and that while two studies showed an increased risk of severe injury in youth cyclists when a motor-vehicle was involved (7, 8), there was no information regarding the characteristics of the drivers involved in these collisions (e.g. age, sex, vehicle type). Moreover, this review has indicated a need for research comparing those bicyclists who are severely injured and those who are not severely injured (6). By using police collision reports, we are able to address these limitations as this dataset will provide youth, driver and environmental characteristics for collisions that result in hospitalization of the cyclist. The aim of this manuscript is to understand the differences in characteristics between youth who, after a BMVC, are reported by police to have suffered 'major injury' or 'fatal injury' (severe injury) and those who were reported by police to be uninjured/treated and released from emergency department (non-severe injury). It is important to understand what characteristics of motorists, cyclists and the environment are contributing to the most severe injuries in order to develop effective primary prevention strategies.

3.4 Methods

This study uses police reports from 2010-2014 in Edmonton and Calgary, Alberta. Youth (<18 years old) BMVCs involved a cyclist riding their bicycle at the time of collision with a motor vehicle that was not parked. Case cyclists were coded by the attending police officer as 'major injury' or 'fatal injury'. Controls were the remaining cyclists who were coded as 'minor injury' or 'no injury'.

Logistic regression was used to estimate crude and adjusted odds ratios (ORs) for hospitalization/fatal injury of the youth bicyclist compared with no/minor injury using STATA v.12.1 (9). Due to the relatively limited number of cases in our data, our multivariable logistic regression models were informed by Classification and Regression Trees (CART), analyzed using the recursive partitioning (rpart v.4.1.2) package in R software (10). CART analysis is described in detail by Breiman et al. (11) but uses an algorithm to split the original data set into subgroups (branches) to generate less heterogeneous groups at each split (i.e. proportion of outcome) within a variable. This process is carried out within subgroups until the model fails to improve according to a given complexity parameter or the branches have reached the minimum amount of observations allowed for a further split, hence becoming a terminal node (leaves). For our analysis, the complexity parameter and minimum node size were adjusted as necessary to ensure that the tree was large enough to understand what exposure variables were important to the outcome, without the tree becoming so large that the model was overfitting. After growing the tree, we are able to identify the variables that contributed most to separating subgroups regarding our outcome (case or control) while catching potential interactions. Within our logistic regression models, this model was further adjusted the environmental risk factors by youth bicyclist age and sex, as these were previously observed risk factors for severe bicyclist injury (12, 13) and may confound results as they relate specifically to the built environment (14).

3.5 Results

423 youth BMVCs were identified; 43 severe injury cases and 380 non-severe controls. The CART approach identified age, sex, driver action, and impact location as important to the outcome in the driver model and age, sex and cyclist action as contributing most to the youth cyclist model outcome (severe vs. non-severe injury). CART analysis identified peak traffic times, traffic control device, road type, driving conditions and intersection status as the most important in our environmental characteristics model. When performing the logistic regression, there were no statistically significant (alpha=0.05) variables that contributed to severe injury after BMVCs in the driver (Table 2) or bicyclist (Table 3) models. Collisions during peak traffic time had lower odds of severe injury than collisions at off-peak hours (Adjusted OR [aOR]: 0.33 ;95% CI: 0.12-0.87). Collisions occurring on divided roads with no physical barrier had lower odds of severe injury than

those with a physical barrier (Table 4; aOR: 0.35; 95% CI: 0.13-0.96). After further adjusting the environmental characteristics model for age and sex of the bicyclist, the ORs for peak time (aOR: 0.33; 95% CI: 0.13-0.93) and road type (aOR: 0.35; 95% CI: 0.13-0.96) remained protective. The presence of a sign (yield, stop or merge) reduced the odds of severe injury after adjustment for bicyclist age and sex (aOR: 0.19; 95% CI: 0.35-0.99).

Table 2. Comparison of characteristics between youth sustaining severe and non-severe injuries after BMVC

Bicyclist Factors	**Severe collisions (%)**	**Non-severe collisions (%)**	**Unadjusted odds ratio (95% CI)**	**Adjusted odds ratio *(95% CI)**
	n=43	n=380		
Bicyclist Action				
Driving Properly	9 (47.37)	104 (50.98)	1.00	1.00
Failure to Yield at Uncontrolled Intersection	5 (26.32)	32 (15.68)	1.81 (0.56-5.78)	1.25 (0.35-4.53)
Traffic Control Device Violation	3 (15.79)	50 (24.51)	0.69 (0.18-2.67)	0.67 (0.17-2.66)
Other (Improper turn/lane change etc.)	2 (10.53)	18 (8.82)	1.28 (0.26-6.43)	1.18 (0.23-6.10)
Age (Years)				
<7	5 (11.62)	27 (7.11)	1.00	1.00
7 to 12	19 (44.19)	214 (56.32)	1.54 (0.79-3.01)	1.35 (0.49-3.75)
13-17	19 (44.19)	139 (36.32)	2.09 (0.72-6.04)	1.43 (0.15-13.85)
Sex				
Female	4 (9.30)	75 (19.74)	1.00	1.00
Male	39 (90.70)	305 (80.26)	2.39 (0.83-6.92)	5.56 (0.71-43.58)
Helmet				
Wearing Helmet	25 (64.10)	183 (55.45)	1.00	-
Not Wearing	14 (35.89)	147 (44.54)	1.43 (0.72-2.86)	-
Speeding				
Not Speeding	20 (90.90)	189 (89.57)	1.00	-
Speeding	2 (9.10)	22 (10.43)	0.85 (0.19-3.92)	-

*Adjusted for Bicyclist Action, Age and Sex

Table 3. Comparison of MV driver characteristics involved in collisions resulting in severe and non-severe injuries to youth bicyclists

Driver Factors	Severe collisions (%)	Non-severe collisions (%)	Unadjusted odds ratio (95% CI)	Adjusted odds ratio* (95% CI)
	n=43	n=380		
Driver Action				
Driving Properly	19 (54.29)	179 (60.68)	1.00	1.00
Failure to Yield at Uncontrolled Intersection	7 (20.00)	67 (22.71)	0.98 (0.40-2.45)	0.83 (0.31-2.25)
Traffic Control Device Violation	2 (5.71)	18 (6.10)	1.05 (0.23-4.86)	1.20 (0.23-6.12)
Backed Unsafely	4 (11.43)	11 (3.73)	3.42 (0.99-11.82)	5.92 (0.34-102.63)
Other (Improper turn/lane change etc.)	3 (8.57)	20 (6.78)	1.41 (0.38-5.20)	1.29 (0.33-5.00)
Age				
16 to 24	7 (17.50)	39 (11.78)	1.71 (0.63-4.64)	1.26 (0.40-4.02)
25 to 39	11 (27.50)	105 (31.72)	0.99 (0.42-2.35)	0.78 (0.29-2.04)
40 to 50	12 (30.00)	114 (34.44)	1.00	1.00
55 to 91	10 (25.00)	73 (22.05)	1.30 (0.53-3.12)	1.19 (0.45-3.12)
Impact Location				
Front Centre	30 (69.77)	206(57.38)	1.00	1.00
Back	4 (9.30)	15 (4.18)	1.83 (0.57-5.89)	0.40 (0.02-7.00)
Left Side	2 (4.65)	48 (13.37)	0.29 (0.07-1.24)	0.29 (0.06-1.35)
Right Side	7 (16.27)	90 (25.07)	0.53 (0.23-1.26)	0.43 (0.15-1.22)
Sex				
Female	13 (31.70)	160 (45.45)	1.00	1.00
Male	28 (68.30)	192 (54.55)	1.79 (0.90-3.58)	1.96 (0.87-4.38)
Speeding				
Not Speeding	25 (92.59)	253 (96.93)	1.00	-
Speeding	2 (7.41)	8 (3.07)	2.53 (0.51-12.57)	-
Vehicle Type				
Passenger Car	18 (43.90)	203 (54.13)	1.00	-
Truck/Van/SUV	20 (48.78)	156 (41.60)	1.44 (0.74-2.83)	-
Commercial Vehicle	3 (7.32)	16 (4.27)	2.11 (0.56-7.95)	-
Alcohol Use				
Impaired by Alcohol	1 (2.56)	0 (0.00)	-	-
Apparently Normal	38 (97.44)	313 (100.00)	-	-

* Adjusted for Driver Action, Age, Impact Location and Sex

Table 4. Comparison of environmental factors in BMVCs resulting in severe or non-severe injuries to youth bicyclists

Environmental Factors	Severe collisions (%)	Non-severe collisions (%)	Unadjusted odds ratio (95% CI)	Adjusted odds ratio* (95% CI)	Adjusted odds ratio† (95% CI)
	n=43	n=380			
Driving Conditions					
Normal	42 (97.67)	357 (93.95)	1.00	1.00	1.00
Poor	1 (2.33)	23 (6.05)	0.37 (0.05-2.81)	0.39 (0.05-3.16)	0.42 (0.05-3.39)
Intersection					
Yes	26 (60.47)	252 (66.32)	0.77 (0.41-1.48)	1.17 (0.45-3.02)	1.36 (0.52-3.57)
No	17 (39.53)	128 (33.68)	1.00	1.00	1.00
Peak Time^					
Yes	6 (13.95)	114 (30.16)	**0.38 (0.15-0.91)**	**0.33 (0.12-0.87)**	**0.34 (0.13-0.93)**
No	37 (86.05)	264 (69.84)	1.00	1.00	1.00
Road Type					
Divided w/ Barrier	19(44.19)	138 (36.32)	1.00	1.00	1.00
Divided No Barrier	6 (13.95)	112 (29.47)	0.39 (0.15-1.01)	**0.35 (0.13-0.96)**	**0.35 (0.13-0.96)**
Undivided Two-Way	8 (18.60)	66 (17.37)	0.88 (0.7-2.12)	0.53 (0.16-1.76)	0.41 (0.12-1.48)
Undivided One-Way	2 (4.65)	8 (2.11)	1.82 (0.39-9.19)	1.50 (0.27-8.44)	1.68 (0.30-9.50)
Other	8 (18.60)	56 (14.74)	1.04 (0.43-2.51)	0.65 (0.18-2.27)	0.56 (0.16-2.04)
Traffic Control Device					
Nothing Present	21 (52.50)	153 (42.27)	1.00	1.00	1.00
Crosswalk	10 (25.00)	54 (14.92)	1.35 (0.60-3.05)	1.11 (0.39-3.13)	1.08 (0.37-3.17
Traffic Lights	7 (17.50)	95 (26.24)	0.54 (0.22-1.31)	0.40 (0.12-1.31)	0.38 (0.11-1.27)
Sign Present	2 (5.00)	60 (16.57)	0.24 (0.06-1.07)	0.21 (0.04-1.07)	**0.19 (0.35-0.99)**
Hit and Run					
Yes	3 (6.98)	52 (13.68)	0.47(0.14-1.59)	-	-
No	40 (93.02)	328 (86.32)	1.00	-	-
Light Condition					
Normal	34 (89.47)	340 (89.71)	1.00	-	-
Poor	4 (10.53)	39 (10.29)	1.02 (0.35-3.04)	-	-
Road Curve					
Straight	21(80.77)	155 (90.12)	1.00	-	-
Curved	5 (19.23)	17(9.88)	2.17 (0.73-6.50)	-	-
Road Grade					
Flat	25	157 (90.75)	1.00	-	-
Graded	1	16 (9.25)	0.39 (0.05-3.09)	-	-
Weekend					
Yes	15 (34.88)	83 (21.90)	1.91 (0.98-3.74)	-	-
No	28 (65.12)	296 (78.10)	1.00	-	-

^ Peak time defined as 6:00am-8:59am or 4pm-5:59 pm on weekdays
* Adjusted for Driving Conditions, Intersection, Peak Time, Road Type and Traffic Control Device
† Adjusted for variables in * as well as cyclist age and sex
note: ***bold*** *indicates significant at 0.05 alpha level*

3.6 Discussion

BMVCs occurring at peak time, on divided roads with no physical barrier or in the presence of road signs were associated with less severe injuries among children and adolescents. It is possible that the road type itself is not reducing the odds of severity, but that these types of roads are targets for traffic calming devices, lower speed limits or lower traffic volume. The apparently protective effect of peak traffic times may be due in part to heavier traffic limiting vehicle speed. Further, this could be due to the so-called “safety in numbers” effect (15). There is evidence from other studies that during the hours of commuting to and from school odds of severe injury in youth are lower (8). The road type may be a proxy for vehicle speed and relative volume. Roads that are divided with a barrier tend to be ‘arterial’ or main roads that connect communities. Roads that are divided without a physical barrier would include roads within a community and demonstrated reduced odds of severe injury in youth involved in BMVCs. Sign presence may indicate the importance of controlled intersections for youth bicyclists, as well as a possible risk of mid-block crossings for youth cyclists, where these types of signs would not be present.

Characteristics such as being less than 15 years of age and being male have been shown as risk factors for severe bicycling injury (12, 13). Personal characteristics in the police collision reports did not influence child and adolescent injury severity in BMVCs. Sex differences may not have been observed as only 18.7% of youth were female, potentially reducing the precision of our OR estimates. Generally, there were more males involved in youth BMVCs, but this may be due to inherent sex differences or simply bicycling more often than females. Furthermore, although the observed OR for severe injury in males was not statistically significantly higher than females, the aOR was relatively large (OR: 5.56; 95% CI:0.71-43.58).

Although helmet use was not a statistically significant factor in reducing odds of severe injury, it is important to consider this behavior since helmets are effective in reducing head injury severity (16) and are mandatory for those under 18 years of age in Alberta. Previous Alberta-based studies observed approximately 93% of youth under 13 years old wearing helmets and 63% of 14-17 year olds wearing helmets when bicycling in an urban environment (17). In our dataset, only 56.4% of youth were wearing helmets. Helmet use may have declined since legislation was initially passed in Alberta in 2002.

There is a paucity of research examining driver characteristics that contribute to severe collision with youth cyclists; however, some risk factors for BMVCs in drivers include being over 60 years old, drug or alcohol use and lack of seat belt usage (12). These risk factors were not observed in this study as there was only one collision where the driver was under the influence of alcohol. It is important to consider that approximately 13% of collisions were 'hit and runs', so it is possible that these risk factors played a role in collisions where police were unable to identify driver characteristics.

Our study has limitations. First, while police collision reports can be a rich source of data, they do not contain factors such as socioeconomic status, speed of the vehicle/bicycle or cyclist experience. Misclassification is possible, where those in our control group may have had their injuries progress in severity after the initial report. However, police reports are generally accurate at identifying severe injuries (18). The selection of this study sample is based entirely on the report of these collisions to police and although this allows the capture of collisions with no injury, underreporting of collisions is a known issue with police report data, especially in cyclists and those under 19 years of age (19). Likely, those who are not reporting collisions are those involved in collisions that do not result in hospitalization. This is a limitation of any collision dataset and future studies should seek to identify those who are not reporting BMVCs to ensure that those who are reporting are truly representative of the population from which case could arise. Third, while it is encouraging to only see 43 severe injuries in two major Alberta cities over five years, this limits data analysis and reduced the precision of our estimated ORs.

There are some potential issues with using police reports for research. For example, the City of Calgary has indicated a need to improve the bicycle collision reporting format and procedure (20). Current police reports make it difficult for the officer to accurately identify primary event and pre-collision action for collisions involving bicyclists. For example, approximately 50% of the youth BMVCs were coded as “struck object” as the primary event; unfortunately, in the case of youth BMVCs this gives us little insight as to what specific actions are contributing to severe injuries.

Future studies should be undertaken to better understand the risk for severe injuries in youth bicyclists. Studies in larger jurisdictions or across jurisdictions may provide better precision of estimates by increasing sample size. These studies should also consider more micro-level environmental factors that could be contributing to youth BMVCs resulting in severe injury.

3.7 Conclusion

Population level data from the two largest cities in Alberta, Canada were used to examine risk factors for severe injury in youth BMVCs. This study used CART as a means of variable selection for multivariable logistic regression model building. Several environmental factors were identified that may contribute to severe injuries to youth bicyclists, indicating a greater need for research that focuses on the environment in which these injuries occur.

3.8 References in Chapter 3

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CHAPTER 4: ADAPTATION OF A CANADIAN CULPABILITY SCORING TOOL TO ALBERTA POLICE TRAFFIC COLLISION REPORT DATA

4.1 Preamble

This chapter seeks to adapt a culpability analysis tool that has been validated in British Columbia to Alberta police traffic reports. This methodological manuscript has been prepared to be submitted to the journal *Traffic Injury Prevention*. Still, there are minor changes to accommodate the formatting necessary for a manuscript-based thesis. Preliminary work related to this manuscript was also accepted for oral presentation at the following conference:

Pitt T, Aucoin J, Graff P, Howard A, Nettel-Aguirre A, McCormack G, Owens L, Anderson M, Rowe BH, Hagel B. Adaptation of a Canadian Culpability Scoring Tool to Alberta Police Traffic Collision Report Data. Canadian Association of Road Safety Professionals Conference, 2018. Victoria, Canada.

4.2 Abstract

Background: Traffic research techniques often require the ability to assign fault in collisions. A Canadian Culpability Scoring Tool (CCST) uses police collision report data and is automated to score driver fault in motor-vehicle collisions (MVCs), while accounting for external factors (e.g., weather conditions). This tool was previously validated using British Columbia police collision report data; however, police collision reports are different between provinces. In order to use this tool for traffic research in Alberta, the tool must be adapted to Alberta data.

Aim: To adapt a previously validated Canadian Culpability Scoring Tool to Alberta police report data.

Methods: Police traffic collision reports from MVCs in Calgary and Edmonton from 2010-2014 were used. Adaptation of the CCST was completed through collaboration with Alberta Transportation, which contributed to face and content validity. Two research assistants, given only the information necessary for scoring, evaluated 175 randomly selected MVCs by hand. Discussion of disagreements between the two, and consultation from Alberta Transportation, informed the rules used in the automation of the Alberta tool. The automation was applied to motorists who were hospitalized after collision as well as all motorists in collision. Logistic regression was used to examine characteristics of the culpable and non-culpable drivers. The results of this tool were also compared with those in the CCST.

Results: The kappa value of inter-rater reliability for the random sample was 0.95 [95% CI: 0.92-0.99]. Of those drivers hospitalized, 1,130 (37.54%) were not-culpable, 1,880 (62.46%) were scored culpable. The culpable group had higher crude odds of being male (OR=1.43, 95% CI: 1.23-1.66) and higher odds of being being culpable when impaired by alcohol (OR=61.10, 95% CI: 22.66-164.75). The culpable group had higher odds of being <25 years old compared with >54 years old (OR=1.72, 95% CI: 1.35-2.20). Driving between 12 am and 6 am had higher odds of being culpable than any other 6-hour time-

block. Direction of the statistically significant results remained when applying the tool to all drivers in collisions. As well, sensitivity analysis, including the removal of single vehicle collisions did not appear to affect the main outcome in a meaningful way.

Discussion: The culpable group, as determined by the Alberta-specific culpability tool, exhibit characteristics that are expected in drivers who are at-fault in collisions. The age groups 25-39 and 40-54 demonstrated slightly different results than the CCST results. However, this is the only difference that exists in the findings of this tool compared with the CCST and could exist due to variability between data sets, rather than the adaptation approach.

Conclusion: It is possible to adapt the CCST to provinces outside British Columbia and assign fault, with 100% consistency, on large data sets. In doing so, we can identify risk factors for collision contribution and not-at-fault drivers who represent the driving source population.

4.3 Background

In traffic research, it is often difficult to determine a control group that fairly represents the population from which a case could arise. Direct assessments of exposure include vehicle kilometers travelled (VKT) while indirect measures include methods such as quasi-induced exposure (QIE). VKT is a fairly general overview of driving behavior that is poorly disaggregated and not readily available (1); furthermore, VKT may not capture risk factors that may change over time (including drug or alcohol use) (2). The QIE technique, first proposed in 1971 by Haight stipulates that drivers in collision who are not-at-fault were essentially "chosen at random" by the culpable driver (3). This principle can be applied to many collisions where the drivers who are not-at-fault approximate the typical driver in the population. Furthermore, these drivers could be disaggregated to vehicle type, time of day or road types (i.e. urban vs. rural) to consider what/when/where they are driving. A similar method of culpability (or responsibility) analysis has been proposed and used over the past several decades as well.

Culpability (or responsibility) analysis has been performed alongside QIE and is fairly similar in that both consider the not-at-fault driver to be representative of the general driving population. However, they differ in that QIE traditionally uses "clean" two-vehicle collisions where one party is at-fault and another is not-at-fault while culpability analysis uses all drivers and compares those not-at-fault to those at-fault. However, in recent years QIE has been expanded to include collisions with more than two vehicles (4) since it has been demonstrated, as a means to validate the randomness assumptions implicit in QIE, that not-at-fault drivers in two vehicle collisions do not differ significantly from those in three vehicle collisions (5, 6). Both techniques are essentially identical and are widely used indirect measures of exposure that can identify not-at-fault drivers who represent the driving population.

Both culpability analysis and QIE require a reliable method of assigning fault. The initial QIE method relied on police officer determination of fault; however, this method, while simple, may be subject to bias of the officer and the so-called "negative halo effect" (7). The "negative halo effect" stipulates that an individual may be considered at-fault more often if the police officer perceives the individual to fit the characteristics that they believe are typically at-fault. Given the potential for bias, there is a need for responsibility analysis techniques that are objective, favour assessment of contribution to the crash and consider environmental or external factors that may also contribute to collisions, rather than perceived legal responsibility.

Since their inception, culpability analysis tools have used a 'scale of fault' where drivers are scored individually on their contribution to the collision across a number of variables (8). This allows for multiple drivers to be at-fault, multiple to be not-at-fault or the ability to assign indeterminate scores. Culpability analysis tools have become increasingly complex and now cover a multitude of external and internal contributing factors. For example, a widely used and validated fault-analysis tool was proposed by Robertson & Drummer in 1994, and considers eight categories (road conditions, vehicle conditions, driving conditions, type of collision, witness observations, law obedience, driving task and level of fatigue) scored from 1-4 in assessing contribution (9).

Culpability analysis tools have been employed across a number of countries including France (10-12), Australia (9), New Zealand (13) and Canada (2, 14). These tools are generally scored by hand, relying on the free-text description in police reports. As well, they have been applied to determine odds of culpability in drivers under the influence of various drugs (9, 11, 12), using cell phones (14), mind-wandering (10) or under the influence of alcohol (2, 15).

This paper will focus on one tool, in particular, a Canadian Culpability Scoring Tool (CCST) that was developed in British Colombia, Canada (2). What makes this tool important for our research is that it was developed with the Canadian climate in mind and accounts for more variations in weather that the Robertson and Drummond tool (developed in New Zealand) may not have considered. Moreover, this tool is fully automated so it can be applied at a population level. While this tool was successful when used on BC police traffic collision reports, police collision reports are different for each province. To that end, this study aimed to adapt the CCST to Alberta Police Report Data. As well, given the lack of consistency in how responsibility tools are defined, adapted and applied (16), there is a need for a meticulous approach to adaption if these tools are to be used for future case-control studies.

4.4 Methods

4.4.1 Data Mapping and Adaptation

Our data come from Alberta Transportation electronic records of police collision reports from 2010 to 2014 for the cities of Edmonton and Calgary. These reports consist of a number of variables relating to environmental conditions, driver characteristics and a short free description of the collision (see Appendix A for example).

The CCST is scored on 7 categories with scores ranging from 1-5. This means a driver can have a minimum score of 7 and maximum of 35. Drivers with a score of ≤13 are considered culpable, those with scores ≥16 non-culpable and scores of 14 and 15 are indeterminate. The seven categories include: Road type, driving condition, vehicle condition, unsafe driving actions, contribution from other parties, type of collision and task involved. The selection and justification of these categories and scores as well as their face, content and concurrent validity as considered by federal experts in traffic safety are described in detail by Brubacher et al. (2). The content of these tools were not amended as the methodology used to achieve the categories for a Canadian climate were previously validated (2). We did, however, engage with traffic safety experts in Alberta to map the CCST categories to the Alberta police collision report data. The mapping of the Alberta Police report categories to the CCST is provided in Figure 2, with a more detailed breakdown of categories in Appendix B.

Canadian Tool	AB Report	Score
1. Road Type		
One Way Traffic	Road Class	
No Ramp	Special Facility or Description	1
Ramp	Special Facility or Description	2
Two Way Traffic	Road Class	
Between Intersection	Collision Location	2
Intersection	Collision Location	3
Ramp	Special Facility or Description	3
Police list roadside hazard or poor design as factor		5
2. Driving Condition		
Road Surface	Surface Condition	
Dry Asphalt	Dry Surface, road condition	1
Dry Gravel	Dry Surface, road condition	2
Wet asphalt	Wet Surface, road condition	2
Wet Gravel	Wet Surface, road condition	3
Road muddy/snow	Muddy Surface	4
Road surface listed as contributory	Contributing road condition	5
Visibility and Weather Conditions	Environmental / Light Condition	
Clear or Cloudy	Environmental Condition Clear	1
If lighting dark with partial or no illumination	Light Condition	2
Rain, smog, smoke, wind	Environmental Condition	2
If lighting dark with partial or no illumination	Light Condition	3
Snow, sleet, hail, fog	Environmental Condition	3
If lighting dark with partial or no illumination	Light Condition	4
Police list visibility or weather as contributory		5
3. Vehicle Condition		
Not a contributory factor in crash	Vehicle Condition	1
Contributory factor in crash	Vehicle Condition	5

Canadian Tool	AB Report	Score
4. Unsafe Driving Actions		
Not obeying laws or unsafe driving	Driver Action / Speed	1
Obeyed laws and driving safely	Driver Action (Driving Properly)	5
5. Contribution from other parties		
No Contribution	Driver Action / Impact Location	1
Contribution	Driver Action / Impact Location	5
6. Type of Collision		
Unsafe Driving	Driver Action / Speed	1
No Unsafe Driving	Driver Action (Driving Properly)	
Multivehicle crash	Vehicle Number	5
Stopped/Parked	Driver Action (Parked Vehicle)	
Lead vehicle in rear end	Vehicle Number	
Third or subsequent vehicle	Vehicle Number	
Loss of control prior to crash	Collision Description	1
Precollision Action	Primary Event	
Striking	Impact Location	*
Indeterminate	Impact Location	*
Struck	Impact Location	*
*Scoring varied based on the precollision action and the impact location		
7. Task Involved		
Unsafe Driving	Driver Action / Speed	1
No Unsafe Driving	Driver Action (Driving Properly)	
Parked, Stopped in traffic	Driver Action (Parked) / Description	5
Turning and backing	Primary Event	2
All other Precollision Actions	Primary Event	1

Figure 2. Mapping of CCST (Canadian Tool) to Alberta police collision report (AB Report) categories

Next, a rule-based scoring system was generated to score each category in a way that would not be reliant on the description field and could be coded into statistical software in a way that would facilitate consistent interpretation. To that end, two research assistants (RAs) were provided with 175 randomly selected multi-vehicle collisions and asked them to score each driver in each collision, by hand, using the rules that were developed in conjunction with traffic experts. The two RAs were given only information necessary to score, meaning that they were blind to driver characteristics including alcohol/drug use, injury severity, age, sex, city and vehicle type. Discussion of disagreements between the two, and consultation with Alberta Transportation personnel, informed the rules used in the automation of the Alberta tool.

The tool was then automated in STATA v.12(17). The coding for most variables was relatively straightforward; however, as in the CCST, combinations of driver action and impact location were used to determine contribution score in the type of collision category. As well, there were issues with missing data in this sample. For example, one-way or two-way road is rarely (less than 3% of our sample) identified in Edmonton police collision reports; however, this is captured in the vast majority (~97%) of collisions in Calgary. By excluding those who were missing we would have systematically excluded an entire city and would reduce the generalizability of tool. To that end, one-way highway listings provided by the City of Edmonton within Bylaw 5590 were used to code collisions occurring on one-way roads. For example, if Road A in collision is 52 avenue NW and Road B is between 107 street NW and 109 street NW then the road was coded as a one way. Each one-way road and potential intersections were confirmed using google maps.

While we were able to remedy these missing data by supplementing with another source, this illustrates some differences between cities in how data were recorded.

4.4.2 Statistical Methods

This statistical analysis is meant to replicate that of the CCST validation in order to examine the comparability of the tools. As such, the role of alcohol was examined in culpability by retaining only collisions that did not involve hit and runs and those where severe injuries occurred, as reported by the police officers. Chi-squared analysis and univariate logistic regression were performed and compared the odds of being in the culpable group vs. the non-culpable group across a number of driver characteristics such as sex, age, alcohol consumption, time of collision and collision type. Our second analysis, a multivariable logistic regression model, examined alcohol as the main exposure while adjusting for age and sex of the drivers. The multivariable logistic regression model in the Brubacher et al. (2) analysis includes urban or rural collision location in their model, but since these data were limited to urban areas only (Calgary and Edmonton) this confounder was addressed through restriction. Sensitivity analysis was performed by examining the effect on odds of culpability while under the influence of alcohol after removing single vehicle collisions. The tool was then applied to the entire data set of multi-vehicle collisions, again, performing chi-squared tests and univariate logistic regression. All statistical analyses were performed using STATA v.12(17).

4.5 Results

4.5.1 Inter-rater reliability

The kappa value of inter-rater reliability for the randomly selected and hand-scored sample of 175 was 0.95 [95% CI: 0.92-0.99], indicating near perfect agreement (18).

4.5.2 Hospitalized drivers

After dropping hit and runs and motorists with indeterminate culpability scores, there were 2,985 hospitalized motorists over our time period: 1,880 (63%) deemed culpable 1,105 (37%) non-culpable (Table 5). The odds of being culpable were higher in males than in females (OR=1.43, 95% CI: 1.23-1.66), had been drinking (OR=20.86, 95% CI: 8.47-51.41), and being impaired by alcohol (OR=61.10, 95% CI: 22.66-164.75). The odds of being culpable were higher in <25 years old compared with >54 years (OR=1.43, 95% CI: 1.23-1.66). The odds of being culpable were also higher when driving between 12 am and 6 am than any other 6-hour time-block. The non-culpable group had lower odds of being 40-54 years of age (OR=0.78 95% CI: 0.63-0.96) than the age group >54 years. After adjusting for sex and age odds of being culpable remained statistically significant for those who had been impaired by alcohol compared with those who had not been drinking (OR=57.92 95%CI: 21.45-156.45). In the sensitivity analysis, where all single vehicle collisions were removed, had been drinking (OR=12.09 95% CI: 4.29-34.07) and impaired by alcohol (OR= 28.10 95% CI: 10.27-76.92) remained statistically significant.

Table 5. Comparison of culpable and non-culpable characteristics in drivers hospitalized after collision

	Non-Culpable (%)	Culpable (%)	OR (95% CI)
Total Drivers	1,130 (37.54)	1,880 (62.46)	
Sex			
Female	480 (43.44)	657 (34.95)	1 (Reference)
Male	625 (56.56)	1223 (65.05)	**1.43 (1.23-1.66)**
Age			
<25	154 (13.93)	435 (23.14)	**1.72(1.35-2.20)**
25-39	364 (32.94)	610 (32.45)	1.02 (0.83-1.26)
40-54	352 (31.86)	449 (23.88)	**0.78(0.63-0.96)**
>=55	235 (21.27)	386 (20.53)	1 (Reference)
Crash Type			
Single Vehicle	27 (2.44)	737 (39.20)	**25.74 (17.38-38.14)**
Multi Vehicle	1078 (97.56)	1143 (60.80)	1 (Reference)
Alcohol Use			
Apparently Normal	1041 (99.14)	1018 (74.91)	1 (Reference)
Had Been Drinking	5 (0.48)	102 (7.51)	**20.86 (8.46-51.41)**
Impaired by Alcohol	4 (0.38)	239 (17.58)	**61.10 (22.66-164.75)**
Had Been Drinking vs Impaired			**7.15 (5.80-8.50)**
Time of Day			
00:01-06:00	92 (8.34)	303 (16.18)	1 (Reference)
06:01-12:00	337 (30.56)	458 (24.45)	**0.41 (0.31-0.54)**
12:01-18:00	460 (41.70)	648 (34.60)	**0.43 (0.33-0.56)**
18:01-24:00	214 (19.40)	464 (24.77)	**0.66 (0.50-0.87)**

Note: ***bold*** *indicates significant at alpha level of 0.05*

4.5.4 All Drivers

Finally, the tool was applied to all 656,594 eligible drivers in MV only collisions wherein 243,935 (37.15%) were deemed not-culpable, 396,133 (60.33%) were deemed culpable and 16,526 (2.52%) were indeterminate (Table 6). The direction of ORs were the same in the entire group compared with the hospitalized group. The magnitude of ORs was similar in the entire group compared with the hospitalized with the largest difference being impaired by alcohol (OR=32.77, 95% CI:27.35-39.25), perhaps due to our ability to more precisely estimate odds in this larger group.

Table 6. Comparison of culpable and non-culpable characteristics in drivers involved in MV collision

		Non-Culpable (%)	Culpable (%)	OR (95% CI)
		243,935 (38.11)	396,133 (61.89)	
Sex				
	Female	98,693 (40.85)	125,922 (38.06)	1 (Reference)
	Male	142,894 (59.15)	204,905 (61.94)	**1.12 (1.11-1.14)**
Age				
	<25	34,312 (14.32)	68,600 (21.16)	**1.52 (1.49-1.55)**
	25-39	83,912 (35.02)	111,510 (34.40)	1.01 (0.99-1.02)
	40-54	74,381 (31.05)	82,203 (25.36)	**0.85 (0.84-0.86)**
	≥55	46,982 (19.61)	61,891 (19.09)	1 (Reference)
Crash Type				
	Single Vehicle	4,242 (1.74)	140,689 (35.52)	**31.12 (30.17-32.10)**
	Multi Vehicle	239,693 (98.26)	255,444 (64.48)	1 (Reference)
Time				
	>00:00 to 06:00	9,892 (4.09)	21,548 (5.52)	1 (Reference)
	>06:00 to 12:00	80,067 (33.09)	127,003 (32.56)	**0.73 (0.71-0.75)**
	>12:00 to18:00	122,695 (50.70)	181,500 (46.53)	**0.68 (0.66-0.70)**
	>18:00-24:00	29,334 (12.12)	60,022 (15.39)	**0.94 (0.91-0.97)**
Alcohol Use				
	Apparently Normal	213,346 (99.81)	244,403 (97.04)	1
	Had Been Drinking	287 (0.13)	2,908 (1.15)	**8.84 (7.83-9.99)**
	Impaired by Alcohol	121 (0.06)	4,542 (1.80)	**32.77 (27.35-39.25)**
Injury Severity				
	None	224827 (94.00)	314178 (96.89)	1
	Minor Injury	13171 (5.51)	8149 (2.51)	**0.44 (0.43-0.46)**
	Major Injury	1160 (0.48)	1828 (0.56)	**1.13 (1.05-1.21)**
	Fatal	24 (0.01)	106 (0.03)	**3.12 (2.03-4.92**

*Note: **bold** indicates significant at alpha level of 0.05*

4.6 Discussion

Results of the Alberta adapted tool were similar to those in the CCST(2). The age groups 25-39 and 40-54 demonstrated slightly different results than the CCST results. All other variables had only slight differences in magnitude and no differences in direction. This indicates that our tool was consistent with the results in the CCST and that the differences in magnitude may be due to variations between the samples or, in the case of alcohol, a difference in the way the variable was split (impaired by alcohol vs. BAC measured in blood). The methodology used to adapt the CCST to Alberta data was carefully built on the methods previously described by Brubacher et al. (2).

The proportion of those who are non-culpable has been described as integral in fulfilling the assumption of culpability analysis that not-at-fault and at-fault drivers are inherently different. If the tool is not "sufficiently harsh" then we may fail to identify the differences that one would expect between the two groups; thus, this application would be unsuccessful in selecting a control group that is representative of the source population of all drivers (19). There are no strict guidelines on what the proper harshness of a culpability tool should be, but research by af Wahlberg has demonstrated that a tool assigning fault to 70% of drivers appears to provide a not-at-fault group of drivers that is more representative of the typical driving population than a tool that assigns 50% as at-fault (19).

Recent responsibility studies that have used or adapted the tool developed by Robertson and Drummer have varied in culpable proportion from 16% (13) to 53% (10). Our tool found 37.15% of those sustaining severe injuries as non-culpable, so these results sit somewhere in the middle for culpability tools in research and are closer to the 30% proportion described by af Walberg. Further, the use of the Brubacher tool in assigning responsibility for collisions, as it relates to cell phone usage while driving, also demonstrated a non-culpable proportion of 37% in 1,248 drivers (14).

Since this study is not combining medical data with police collision reports, there is a lack of precision in alcohol measurement demonstrated in the CCST. Three levels of alcohol exposure were used as opposed to hospital measurement of blood alcohol concentration (BAC): Apparently Normal, Had Been Drinking (<0.08 BAC) and Impaired by Alcohol (>0.08 BAC). Despite this limitation, there is an observable increase in odds across the three levels and a comparison of odds between had been drinking and impaired by alcohol was also statistically significant (OR: 7.15; 95% CI: 5.80-8.50). This study observes ORs of 61.10 (22.66-164.75) when considering the role of alcohol impairment in responsibility of the severe injury group. This is in line with previous research that has identified similar values for relative risk at higher BACs (0.15-0.25 BAC) and odds of collision (20) and odds of alcohol related fatal collision (21). As well, given that our split of BAC is from 0.08 to (in theory) 1.00, and that ORs of alcohol use and culpability tend to increase fairly drastically at very high levels of BAC (20, 21), it is reasonable to expect that this spread might be reflected in our observed ORs.

It has been described that those collisions that result in hospitalization/fatality could be the most complete due to severity and are indicative of "ground-truth" in terms of describing differences in at-fault and not-at-fault drivers (22). That our results hold between the severe injury cases and all levels of severity may indicate a robustness of our adapted tool that is less influenced by the severity of collision.

We chose to compare single vehicle collisions to multivehicle collisions as was done in the CCST. However, while we speculate that it is likely drivers in single vehicle collisions will be culpable more often than those in multivehicle collisions, in this particular analysis it seems to be an unfair comparison. Since being in a single vehicle collision is part of the culpability scoring tool it seems to be a self-fulfilling prophecy that the culpable and non-culpable groups would differ significantly in the proportion of single vehicle collisions. For this reason, any culpability study should be wary of analyzing variables that are directly or indirectly included in the assessment of responsibility.

Overall, our tool was harsh enough to identify a culpable group that exhibits risk factors for causing collisions that are expected. Further, this group was demographically different than the not-at-fault group. Our analysis was similar to that of Brubacher et al. (2) and demonstrated consistent results; moreover, our ORs align with those described in the literature. Last, our tool is able to maintain the observed results across collisions of all levels of injury severity. The consistency of our results indicates a successful adaptation of the CCST to the Alberta police collision report data, that this tool could be adapted to other provinces and that this methodology could be used to identify risk factors for collisions in the future.

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CHAPTER 5: IDENTIFYING MOTORIST RISK FACTORS IN YOUTH BICYCLE-MOTOR VEHICLE COLLISIONS

5.1 Preamble

This manuscript uses the tool developed in the previous chapter to identify a control group of motorists. These motorists are meant to represent the typical driver in Calgary and Edmonton from 2010-2014 and their characteristics are compared with the motorists who were involved in youth BMVCs over the same time frame. This manuscript was developed with the intention to be submitted to *JAMA Pediatrics*. Slight modifications to the structure have been made for the manuscript-based thesis. Preliminary work related to this manuscript was also accepted for oral presentation at the following conference:

Pitt T, Graff P, Howard A, Nettel-Aguirre A, McCormack G, Owens L, Anderson M, Rowe BH, Hagel B. Identifying Motorist Risk Factors for Paediatric Bicycle-Motor Vehicle Collisions. Canadian Association of Road Safety Professionals Conference, 2018. Victoria, Canada.

5.2 Abstract

Background: Bicycle-related injuries are among the most common injuries during recreational activities for children in Canada. Serious and fatal injuries most commonly result from BMVCs. Factors associated with BMVCs need to be identified to develop effective primary prevention strategies. To date, studies have typically focused on youth (<18 years of age) risk factors rather than driver or environment BMVC risk factors.

Aim: To undertake a case-control study design that will determine the driver characteristics contributing to youth BMVCs.

Methods: Edmonton and Calgary police collision report data from the years 2010-2014 were used. From these data, 423 youth BMVCs and 423 drivers (i.e., cases) involved in those collisions were identified. The controls were drivers who, over the same period, were involved in collisions but deemed not-at-fault using an automated culpability analysis. This control selection uses the quasi-induced exposure method, which indicates that drivers who are not-at-fault in collisions are representative of the typical driver (source population). Descriptive statistics, including proportions, median and interquartile range (as appropriate) were used to describe the characteristics of the two groups involved. Logistic regression was used to examine the differences in characteristics of drivers in our control group and those involved in BMVCs. Multivariable logistic regression was informed using purposeful selection techniques.

Results: 423 motorists involved in BMVCs were identified, as were 239,935 not-at-fault control drivers. The adjusted model indicated that drivers over 55 years of age had higher odds of being involved in youth BMVCs compared with drivers between 25-39 years of age (aOR:1.32; 95% CI: 1.00-1.77). Driving between 00:01hrs-06:00hrs (aOR:0.30; 95%CI: 0.12-0.71) or 06:01hrs-12:00hrs (aOR:0.46; 95%CI: 0.35-0.61) reduced the odds of being involved in youth BMVCs compared with 12:01hrs-18:00hrs while driving between 18:01-24:00hrs increased the odds (aOR:1.44; 95% CI: 1.11-1.88). Driving a truck/van reduced the odds of collision compared with passenger cars (aOR:0.67; 95% CI:0.47-0.94).

Discussion: This study helps to highlight motorist characteristics in youth BMVCs. In doing so, we hope to inform primary prevention strategies for the motorists and environment. Culpability analysis tools and quasi-induced exposure techniques are typically applied to motorists to identify transient exposures; however, this study demonstrates that these techniques are possible in vulnerable population collisions.

5.3 Background

Bicycling is a popular form of active transportation in Canada, with an estimated 12 million Canadians bicycling each year (1). The youngest age groups have the highest participation; for example, 86% of those aged 12-15 years report bicycling at least once a year (1). Bicycling can have a number of physical, environmental and mental health benefits (2) as well as increased independent mobility in youth (<18 years of age) (3). However, bicycle-related injuries are among the most common injuries during recreational activities for youth in Canada (4). Youth cyclists are of a particular concern since, compared with adults, they may not have the situational awareness, cognitive or motor skills to safely ride bicycles in the current road structure (5-7). Not only is the sheer volume of injury a public health concern, but the perceived danger and in particular traffic risk associated with active transportation has been identified as a deterrent by both youth and parents (8, 9). The perception of risk is well-received since, perhaps for obvious reasons, the involvement of a motor vehicle (MV) in a bicycle collision increases risk of severe injury in youth bicyclists (10). Bicycling injuries and collisions may act in a vicious cycle; if youth are deterred from bicycling due to risk then there may be fewer individuals regularly bicycling thereby reducing the “safety in numbers” effect (11). What is more, in

Alberta, youth under 14 years of age are not permitted to operate a MV, so it may be unreasonable to expect that these youth in particular fully understand what is feasible in terms of a motorist's ability to see and react to other road users. Factors associated with youth bicycle-motor vehicle collisions (BMVCs) need to be identified to develop effective primary prevention strategies as a means to both reduce injury rates and potentially improve regular physical activity levels in youth.

The research in youth BMVCs has focused on youth factors including age, sex, clothing, helmet use (12), speed while bicycling and bicycling education. However, despite being equally involved, there is a relative paucity of research examining driver factors in youth BMVCs. The consequences of focusing only on youth involved in MV collisions has been considered previously (13); however, in studying only what youth can do to avoid collisions we place disproportionate responsibility for injury prevention on a group less equipped to manage the risks than motor vehicle drivers. Consideration of parties involved is imperative to fully understand the complexities of youth BMVCs and develop primary prevention strategies.

This study aimed to first broadly describe the child, driver and environmental characteristics of these collisions. Our primary aim is to determine the driver characteristics contributing to youth BMVCs.

Within traffic safety research and in particular, youth BMVCs, it can be difficult to establish a control population or source population norm. Direct measures such as vehicle kilometers travelled may be unable to identify potentially important risk factors or behaviours that may change moment to moment (i.e. cell phone use), so principles from culpability analysis were applied in this study. Culpability analysis has been used to identify risks of collision associated with cell phone use (14), various drug use (15, 16) and alcohol consumption (17, 18). This analysis is similar to quasi-induced exposure (QIE) in that it selects not-at-fault drivers as controls based on the principle that drivers who are not-at-fault in collisions are representative of the general driving population (source population) (17, 19-21). The QIE and culpability analysis studies that employ this reasoning rely heavily on the randomness assumption. Meaning that these not-at-fault drivers are essentially chosen at random by at-fault drivers. If these drivers are truly chosen at random and therefore approximate the driving population then they could be used as a control group for any type of collision over the same time period. To that end, a study design where drivers who are involved in youth BMVCs are compared with this representative group of the source population was chosen.

5.4 Methods

Edmonton and Calgary police collision report data from the years 2010-2014. From these data 423 youth BMVCs were included (i.e., cases). In order to be included, collisions must have involved youth who were on their bicycle at the time of collision and motorists must have been in their vehicle at the time of collision. A previously validated Canadian Culpability Scoring Tool (17) that was adapted and automated to score fault in Alberta police collision report data was applied. Although there is "little to gain" from a 4:1 control to case ratio (22), the controls in this study come at virtually no price methodologically. Since the culpability tool is automated, the time to identify controls is negligibly longer for all individuals in the dataset than it is for (423*4) 1692; therefore, all eligible controls were retained.

Descriptive statistics, including proportions, median and interquartile range (as appropriate) were used to describe the characteristics of the two groups involved. The independent variables of interest were only considered if those variables were not used in the assessment of fault of drivers in MV-MV collisions. Given that controls were assigned based on the variables in this tool it would be unreasonable to compare, for example, odds of collisions occurring at intersections since this is considered in determining if the driver in a MV-MV collision was at fault or culpable.

Eight variables that may be influencing risk of youth BMVCs were examined. Some variables such as seat belt use, driver age and driver sex have been examined previously in BMVCs (all ages) (23). Other variables, such as driving without a passenger (24), have been observed to increase risk of all types of collision.

Chi-square tests of proportions were performed across all nine variables. Univariate logistic regression was used to inform our multivariable model, which followed the Bursac et al. methodology of purposeful variable selection (25); the original paper describes this methodology in detail. A liberal p-value, chosen a priori, of 0.2 for initial inclusion of variables, an alpha level of significance of 0.05 and a shift in 20% of the beta point estimates for confounding were used. The 0.2 p-value and 20% confounding have been assessed and recommended in other work when applying purposeful variable selection (26).

Several sensitivity analyses in our model building were used. First, all data available were included in the analysis then, only complete cases and last, “outliers” with implausible values for age (e.g., >99 years old) were removed. The variables that were included in each of these models were compared as well as the direction, statistical significance and magnitude of association for those variables. Potential interaction terms were assessed using likelihood ratio tests. Hosmer-Lemeshow tests were used to assess model goodness of fit.

5.6 Results

423 motorists involved in youth BMVCs and 239,935 not-at-fault control drivers were identified. BMVCs occurred with the highest proportions in daylight (90.9%), with dry road conditions (94.6%) and clear environmental (95.8%) circumstances (Table 7). June and July had the highest frequency for BMVCs with 84 and 75, respectively. The univariate analysis (Table 8) indicated that driving between 00:01hrs-06:00hrs had lower odds (OR=0.30; 95%CI: 0.13-0.67) of youth BMVCs than driving between 12:01hrs-18:00hrs; as did driving between 06:01hrs-12:00hrs (OR=0.73; 95%CI: 0.71-0.75). Driving between 18:01hrs-24:00hrs increased odds (OR=1.40; 95%CI: 1.09-1.80) of youth BMVCs compared with 12:01hrs-18:00hrs. The univariate analysis indicated that light trucks/vans had lower odds of BMVCs compared with passenger cars (OR=0.64; 95%CI: 0.46-0.88). Time of day and vehicle type were included in the next model, as were the variables: passengers, age group, alcohol impairment and day of week. Likelihood ratio tests for interaction between age/time of day and age/vehicle type were not significant at an alpha level of 0.05. After assessing potential interactions, only the statistically

significant variables within the model were retained. There was no confounding when removing variables that were not statistically significant, nor was there confounding when adding sex or seatbelt use to our model. Thus, the final model for our analysis is presented in Table 9.

Table 7. Characteristics of youth BMVCs

	n (%)
Month of Collision	
January	3 (0.71)
February	3 (0.71)
March	8 (1.90)
April	26 (6.16)
May	66 (15.64)
June	84 (19.91)
July	75 (17.77)
August	58 (13.74)
September	54 (12.80)
October	38 (9.00)
November	5 (1.18)
December	2 (0.47)
Light Condition	
Daylight	379 (90.89)
Darkness	14 (3.36)
Sun glare	24 (5.76)
Surface Condition	
Dry	386 (94.61)
Wet	17 (4.17)
Slush/Snow/Ice	4 (0.98)
Loose Surface Material	1 (0.25)
Environmental Condition	
Clear	388 (95.80)
Raining	15 (3.70)
Snow	2 (0.49)
Hit and Run Status	
Yes	55 (13.00)
No	368 (87.00)
Motorist Age (Years)	
Mean age	43.08
Median age	42
Age Interquartile Range	23

Table 8. Univariate logistic regressions analyses comparing characteristics of not-at-fault controls with motorists involved in youth BMVC

	Control Drivers (%)	Drivers in BMVC (%)	OR (95% CI)	p-value
	243,935	423		
Sex				
Female	98,693 (40.85)	173 (44.02)	1 (Reference)	-
Male	142,894 (59.15)	220 (55.98)	0.88 (0.72-1.07)	0.202
Age				
<25	34,312 (14.32)	46 (12.40)	0.97 (0.69-1.36)	0.860
25-39	83,912 (35.02)	116 (31.27)	1 (Reference)	-
40-54	74,381 (31.05)	126 (22.96)	1.22 (0.95-1.58)	0.114
>=55	46,982 (19.61)	83 (22.37)	1.28 (0.96-1.69)	0.088
Passengers				
None	205,523 (85.53)	369 (88.28)	1 (Reference)	-
Youth Passenger	8,692 (3.62)	15 (3.59)	0.96 (0.57-1.61)	0.881
Adult Passenger	21,826 (9.08)	27 (6.46)	0.69 (0.46-1.02)	0.062
Youth and Adult Passengers	4,244 (1.77)	7 (1.67)	0.92 (0.43-1.94)	0.824
Time				
00:01-06:00	9,892 (4.09)	6 (1.43)	**0.30 (0.13-0.67)**	**0.004**
06:01-12:00	80,067 (33.09)	82 (19.57)	**0.73 (0.71-0.75)**	**<0.001**
12:01-18:00	122,695 (50.70)	248 (59.19)	1 (Reference)	-
18:01-24:00	29,334 (12.12)	83 (19.81)	**1.40 (1.09-1.80)**	**0.008**
Alcohol Impairment				
Apparently Normal	213,346 (99.94)	351 (99.72)	1 (Reference)	-
Impaired By Alcohol	121 (0.06)	1 (0.28)	5.02 (0.70-36.05)	0.108
Seatbelt				
No Seatbelt	1,135 (0.53)	1 (0.31)	1 (Reference)	-
Seatbelt	212,777 (99.47)	321 (99.69)	1.71(0.24-12.21)	0.591
Day of Week				
Weekday	193,565 (79.69)	324 (76.78)	1 (Reference)	-
Weekend	49,326 (20.31)	98 (23.22)	1.19(0.95-1.50)	0.126
Vehicle Type				
Passenger Car	119,597 (49.22)	221 (53.13)	1 (Reference)	-
Light Truck/Van	38,330 (15.77)	45 (10.82)	**0.64(0.46-0.88)**	**0.006**
Minivan/SUV	74,068 (30.48)	131 (31.49)	0.96(0.77-1.19)	0.691
Commercial/Other	11,004 (4.53)	19 (4.57)	0.93(0.58-1.49)	0.777

Table 9. Comparing control drivers with drivers involved in youth BMVC

	Control Drivers (%)	Drivers in BMVC (%)	aOR (95% CI)	p-value
Total Drivers	243,935	423		
Age				
<25	34,312 (14.32)	46 (12.40)	0.89 (0.63-1.27)	0.544
25-39	83,912 (35.02)	116 (31.27)	1 (Reference)	-
40-54	74,381 (31.05)	126 (33.96)	1.28 (0.99-1.65)	0.058
>=55	46,982 (19.61)	83 (22.37)	**1.32 (1.00-1.77)**	**0.05**
Vehicle Type				
Passenger Car	119,597 (49.22)	221 (53.13)	1 (Reference)	-
Light Truck/Van	38,330 (15.77)	45 (10.82)	**0.67 (0.47-0.94)**	**0.019**
Minivan/SUV	74,068 (30.48)	131 (31.49)	0.91 (0.72-1.16)	0.455
Commercial/Other	11,004 (4.53)	19 (4.57)	1.02 (0.62-1.68)	0.940
Time				
00:01-06:00	9,892 (4.09)	6 (1.43)	**0.29(0.12-0.71)**	**0.006**
06:01-12:00	80,067 (33.09)	82 (19.57)	**0.46(0.35-0.61)**	**<0.001**
12:01-18:00	122,695 (50.70)	248 (59.19)	1 (Reference)	-
18:01-24:00	29,334 (12.12)	83 (19.81)	**1.44(1.11-1.88)**	**0.007**

Note: Adjusted for Time, Vehicle Type and Age.

Age group was not statistically significant in our crude analysis, but in the adjusted model drivers over 55 years of age had higher odds of youth BMVCs compared with drivers between 25-39 years of age (OR=1.32; 95% CI: 1.00-1.77). Driving between 00:01hrs-06:00hrs (OR=0.30; 95%CI: 0.12-0.71) or 06:01hrs-12:00hrs (OR=0.46; 95%CI: 0.35-0.61) continued to reduce the odds of youth BMVCs compared with 12:01hrs-18:00hrs while driving between 18:01-24:00hrs continued to increase the odds (OR=1.44: 95% CI: 1.11-1.88). Driving a truck/van reduced the odds of collision compared with passenger cars. Hosmer-Lemeshow tests for goodness of fit were applied, where the data were split into 10 groups and, because of the large sample size, 50 groups. Neither test indicated poor fit with p-values of 0.979 and 0.985, respectively.

Removing outliers did not affect the observed results in a meaningful way. To better understand missing data, the analysis was repeated with the data missing because "the driver fled in a hit and run" added as another level in our categorical variable. Then, all individuals who had data that were missing for no obvious reason. The final output of this sensitivity analysis model contained the same variables from the original model (virtually no change in significance or direction/magnitude of effect), but also included driver sex and alcohol impairment as confounders. These two variables were maintained in this sensitivity analysis as they confounded the age category "missing due to hit and run," but had virtually no influence on all other variables.

5.7 Discussion

Age, vehicle type and time of day were identified as significant factors in youth BMVCs. Older drivers (over 55) had higher odds of being in a youth BMVC; however, younger drivers (<25 years of age) did not. This is in line with a quasi-induced exposure study performed by Matinez-Ruiz examining all ages BMVCs (23). Furthermore, while that same study identified drug use and lack of seatbelt use as increasing the odds of BMVCs, this study did not observe these results. With regard to drug use, there were no drivers coded as under the influence of drugs at the time of collision in the case group; therefore, drug use is either not playing a role in these collisions in our dataset or there is a systematic failure to accurately assess drug use in these collisions. Overall, there was a fairly high level of seatbelt use in our data. This may be why lack of use is not playing a statistically significant role. The high proportion of seatbelt use may be due to successful public health strategies promoting or legislating proper use of seatbelts, but that legislation may also incentivize those who are not wearing seatbelts at the time of collision to lie about their compliance, if given the opportunity.

With youth cyclists, one would expect the vast majority to bicycle during daytime hours, so odds of BMVCs at night time should decrease. While this finding was observed for the time block 00:01hrs-06:00hrs, the odds of youth BMVCs were higher in the time block 18:01hrs-24:00hrs. Of note, Alberta cities typically reduce 50km/h zones to 30km/h zones around schools and playgrounds during times when the city would expect youth to be attending schools or playgrounds. However, during the period of study, there would be no speed limit reductions near schools during summer months, when a large proportion of these collisions occurred (51.42% from June to August). The city of Calgary reported a significant reduction in pedestrian collisions since enforcing speed limit reductions near schools in the same manner as near play grounds (every day of the year from 07:30hrs to 21:00hrs), especially during the 17:30hrs-21:00hrs time block (27). Since this evening time slot sees the highest odds of BMVCs and given the success of the City of Calgary, it may be reasonable to employ province-wide legislation that enforces year-round speed limit reduction around school zones.

Driving with a passenger has been shown to reduce risk of MV collisions (24). This effect was not observed, at a statistically significant level, in youth BMVCs. Passengers were coded as adult or youth as these two passenger types may influence driving behaviour in different ways. Although the effect of adult passengers was not statistically significant, the point estimate of the odds ratio (0.69; 95% CI: 0.46-1.02), bordered on statistically significant and was in line with previous literature in terms of direction of effect.

Alcohol impairment was only seen in one youth BMVC. While the proportion appeared to be higher than in our control group, it was not statistically significant. Given the relatively few cases of alcohol impairment in these collisions it may be difficult to make statistical inferences and given that the majority of collisions occurred during the daytime alcohol might not be playing as large of a role for motorists when compared with other forms of MV collisions.

The weather conditions for these collisions were generally favourable, since youth seem more likely to bicycle during the day, when it is sunny and clear. With regard to built environment features, future studies should consider more micro-level environmental factors such as potential traffic calming devices.

This study's biggest strength is the access to population level data that allows for the comparison of a large group of controls with 423 cases. This study is limited by the ability to make statistical inferences for some variables; for example, few instances made it difficult to assess factors such as alcohol and drug use. Still, the fact that over a five-year period there was only one youth BMVC where a driver was shown to be impaired by alcohol indicates that this is likely not the main factor in these collisions.

Furthermore, a recent meta-analysis indicates that police collision reports may be subject to underreporting for all collisions, with the most underreporting occurring among cyclists (28). The only inherent difference between those who report collisions and those who do not are likely those that result in minor or no injury to the cyclist; however, the main outcome of this study is not dependent on the injury severity of the youth cyclist.

While police reports offer a wealth of information, they do not contain every factor that may be at play. Factors such as cell phone usage at the time of collision were not captured since there is no category for the officer to identify this behaviour in Alberta police collision reports. This is potentially an important factor for youth BMVCs that merits future research, but within these data is not considered.

5.8 Conclusion:

This study helps to highlight often ignored motorist characteristics in youth BMVCs. In doing so, we hope to inform primary prevention strategies for the motorists and environment. Culpability analysis tools and quasi-induced exposure techniques are typically applied to motorists to identify transient exposures; however, this study demonstrates that these techniques can also be applied to vulnerable population collisions.

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CHAPTER 6: DISCUSSION

6.1 Summary of Findings

The main aim of this thesis was to identify risk factors related to youth BMVCs. This was accomplished through several objectives. First, environmental, driver and bicyclist factors related to severe injury of the youth cyclist after a BMVC (presented in chapter 3) were examined. Second, in chapter 4, a Canadian Culpability Scoring Tool was adapted to Alberta police collision report data. Last, in an effort to identify motorist characteristics for BMVC, drivers who are representative of the Alberta driving population were compared with drivers involved in a youth BMVC (presented in chapter 5) using the adapted culpability scoring tool. All three objectives use Alberta Police Traffic Collision Report data from Calgary and Edmonton, January 2010 to December 2014.

6.1.1. Youth bicyclist injury severity related to motor vehicle collision

The first objective was accomplished by comparing youth who had sustained severe injury after BMVC with those who were not hospitalized, having no or minor injuries based on police officer assessment. Comparisons of youth characteristics, motorist characteristics and environmental characteristics identified that presence of signage reduced the odds of severe collision, as did collisions occurring during peak time (6:00am-8:59am or 4pm-5:59 pm on weekdays) and collisions occurring on roads that were divided without a physical barrier.

This study contributes to the literature examining the characteristics that contribute to severe injury in youth BMVCs. This study not only examines those who are severely injured, but also considers the differences between those who are severely injured and those who were not. The study is based on the notion that those youth who are involved in BMVCs could have been severely injured. Through an injury prevention lens, there is a reason why some are hospitalized and some are not; that is, the outcome is not due purely to chance. By understanding risk factors that may be associated with severe injury we can take steps to consider the role of preventative measures.

The results of our study indicated only environmental exposures significantly contributed to severe injuries. It is important to note that, while not statistically significant, there were individual characteristics that may be important to severe injury as well. For example, being male indicated an OR that bordered on significant with wide confidence intervals. This may be due to the fact that females made up a relatively small proportion of youth BMVCs in general (~19%).

Overall, the findings of this study suggest that environmental factors appear to be playing a significant role in injury severity of youth bicyclists involved in BMVCs. Future research should seek to understand environmental factors that may be working within, or in conjunction with, the environmental factors described in this study.

6.1.2 Adaptation and Application of a Canadian Culpability Scoring Tool to Alberta Police Traffic Collision Report Data

The second objective of this thesis was to adapt and automate a Canadian culpability analysis tool to Alberta police traffic collision report data in order to identify drivers who represent the typical driver in Calgary and Edmonton from 2010-2014. Automated culpability analysis tools offer the ability to assign fault in collisions with 100% consistency and across large datasets. A culpability tool that had been previously validated on British Columbia police traffic collision report data (1) was adapted to Alberta police collision report data. This tool is based on a tool by Robertson and Drummer (2), but takes into account Canadian weather conditions.

As part of the adaptation, this study identified risk factors for being at-fault in a collision that are expected and had been shown in the Brubacher et al. analysis (1) for drivers hospitalized after collision. Factors included higher odds of being at-fault when drinking and higher odds of being at-fault when impaired by alcohol; as well, being a male, being in a single vehicle collision, driving at night time, and being under 25 years of age demonstrated increased odds of being at-fault. Harshness of the tool to assign fault was similar to the Canadian Culpability Scoring Tool (CCST) and all variables were consistent with the CCST with the exception of the age groups 25-39 and 40-54. It is possible that this is due to differences in the study population itself and that it may be unrealistic to expect identical results across all jurisdictions. Similar to the CCST, adjusting for age and sex did not affect the significance of alcohol consumption and fault, nor did the removal of single vehicle collisions from the analysis. The tool was used to assign fault across all

MV collisions and although there were some changes in magnitude, results remained the same as in the hospitalized collisions.

The third objective of this thesis was to undertake a case-control study to identify motorist and environmental characteristics that contribute to BMVCs. To that end, we then applied the culpability analysis tool to identify motorist risk factors for youth BMVCs. This novel approach used the not-at-fault drivers as control drivers who were then compared with drivers involved in BMVCs. Older drivers (≥55years old) and driving between 18:01hrs-24:00hrs demonstrated higher odds of youth BMVCs. As well, driving a light truck or van, driving between 00:01hrs-06:00hrs and driving between 06:01hrs-12:00hrs had lower odds of youth BMVCs.

The application of a culpability analysis tool to establish a control group of drivers who could be compared with those involved in youth BMVCs is novel in methodologic application, but also adds to the youth BMVC literature by considering motorist characteristics. The mechanism as to why light trucks/vans reduced the odds of youth BMVC is unclear, but we could speculate that the visibility of these vehicles could improve the ability of the driver to locate and avoid youth bicyclists. As well, that evening hours see the highest odds of youth BMVCs is important given the current Alberta policies surrounding speed limit reductions around schools and playgrounds. Given that this is the time of day when youth BMVCs have the highest odds of occurrence, it may be important for policy-makers to consider traffic calming in areas where youth are likely to bicycle at a time when collision risk is highest.

6.2 Limitations

The limitations within each of these studies could have an effect on internal and external validity. This section will describe potential mechanisms and possible direction/magnitude of effect, if possible, for selection bias, misclassification bias, confounding and generalizability for this thesis.

6.2.1 Selection Bias

Selection bias occurs when the sample being studied is not representative of the population from which this sample is drawn leading to a distortion in the effect estimate (3). Though case selection can be a validity issue in case-control studies, selection bias is generally a concern with regard to the representativeness of the control group. That is, how well the control group represents the exposure distribution of the population from which cases could have arisen. Both chapters 3 and 5 employ a case-control methodology and as such the representativeness of the control groups for each will be examined.

First, in chapter 3 control selection is based on the severity of injuries sustained by the youth cyclist. BMVCs that resulted in severe injury were considered as cases. Those collisions where the youth cyclists sustained non-severe injuries were considered the controls. This control selection is dependent on the reporting of BMVCs that did not result in severe bicyclist injury. While it is expected that the vast majority of cases to be reported due to the nature of severity (and likely need for emergency medical services) we may not see the same level of reporting in collisions that do not result in severe bicyclist injuries. If those involved in non-severe youth BMVCs who do not report the collision differ from those who do, then there could be selection bias. For example, cyclists who are struck but are uninjured may be less willing to report a collision if they are not wearing their helmet for fear of legal consequences. If this happens on a large enough scale then there would be an over representation of cyclists wearing helmets in the control group, thus biasing the results towards a protective effect of helmet use. Still, with regard to this particular example, there is a lower proportion of helmet usage than has been observed in previous school studies in Alberta (4).

In chapter 5 the controls of not-at-fault drivers were used, which is based on the adaptation of an Alberta-specific culpability scoring tool (described in chapter 4). Selection bias could occur if the controls for this study were not truly representative of the driving population from which drivers involved in youth BMVCs could arise. Underreporting has been identified as an issue with police collision report data in other jurisdictions and could occur in ours. Younger drivers (under 19 years old) may underreport collisions more often than all other ages (5). If this is the case in Alberta, and this age group is at-fault more often in collisions then there could be underestimation of individuals under 19 years of age in the at-fault group of drivers, due to underreporting. This mechanism would not affect the results of chapter 5 since the bias described would only underestimate those in the at-fault group.

The control selection for chapter 5 is based on principles from QIE and culpability analysis; QIE and culpability analysis have been studied over the past several decades and there have been a number of studies that have examined and validated the underlying principles involved in these approaches (6-8). The process by which these assumptions have been examined is described in detail throughout chapter 1 as well as chapters 4 and 5. By building on a previously validated tool and meticulously ensuring that the adapted tool produced results in line with previous literature that the potential selection bias, due to an improper assessment of culpability, is attenuated.

6.2.2 Misclassification Bias

Misclassification bias refers to error in how information on exposure, outcome or a confounder has been categorized (3). Misclassification errors could be differential (affect one group more than the other) or non-differential (equal error in comparison groups) (3). Misclassification could have affected the results in chapter 3. It is possible that those youth who were originally coded as no/minor injury could see symptoms or injury progress to a point that required hospitalization well after the police report had been submitted. In this situation, there would be a misclassification of individuals who should be cases into the control group. For example, some individuals may not have been wearing a helmet at the time of collisions and sustained a brain injury that did not present serious symptoms until several days after collision. In this situation, the youth would have already been considered a control who was not wearing a helmet, thus underestimating the effect of helmet use on the role of reducing severe injury.

When generating the rules for the culpability analysis culpability was assessed blind to factors that may influence our interpretation of the collisions (i.e. alcohol consumption, age and sex). After doing so a rule-based, automated, code to assign culpability to collisions was generated and after assigning culpability the differences in the culpable and non-culpable groups were examined. Finally, multiple sensitivity analyses to ensure that the observed findings were robust were performed. These sensitivity analyses included removal of single driver collisions, removal of hit and run collisions, consideration of the role that missing hit and run data may have had, consideration of all missing data as another level within our analyses as well as a comparison of results between groups scoring at different levels of culpability (Appendix C). These steps were taken to ensure that culpability was scored as objectively as possible; still, the data that are recorded by the officer may be subject to bias. For example, if an individual is involved in a collision and under the influence of alcohol, it may be possible that the officer will complete the report less forgivingly than if the individual was not under the influence. This would lead to an overestimation of the effect of alcohol on culpability by misclassifying individuals under the influence, but not necessarily at-fault, into the culpable group. However, given the established risk of causing a collision under the influence of alcohol (9), it is unlikely that a substantial number of drivers were under the influence, but not-at-fault.

6.2.3 Confounding

Confounding is an independent risk factor for the outcome, related to the exposure of interest, but is not on the causal pathway between exposure and outcome (3). Police collision reports offer dozens of variables that can be measured and accounted for. However, collisions are complex and may include unmeasured variables that could be affecting our results.

Police reports offer some information on the built environment, but do not contain information on built environment factors such as traffic calming devices. Traffic calming may include the installation of infrastructure that is designed to intentionally reduce traffic speed and/or traffic volume (e.g. speed humps, road narrowing, turn prohibitions). The presence of these devices was not noted in police collision reports, so there is a possibility that non-severe collisions were not severe due to these devices rather than the observed effects. For example, there were lower odds of BMVCs resulting in severe injury to the youth cyclist on roads that were divided with no barrier. It is possible that the road type itself is not reducing the odds of severity, but that these types of roads are targets for traffic calming devices, lower speed limits or lower traffic volume. That is, roadways that are divided with barrier tend to be main (arterial/skeletal) roads and that common traffic calming techniques, for example speed humps, are generally not advisable on these roadways.

The relationship of road type and injury severity could also be influenced by unmeasured individual factors. For example, police reports do not include personal information for parties involved such as socioeconomic status. Low family socioeconomic status has been identified as a possible risk factor for severe injury in youth and may be a proxy for the environment in which they bicycle (10). The environment in which low socioeconomic status individuals live may include more main roadways (11) (i.e., divided with barrier roads). It is possible that this effect of low socioeconomic status could be confounding the association between road type and severe injury in youth BMVCs.

6.2.4 Sample Size

Within chapter 3 the analysis was limited by having 43 cases. If we submit to the rule of thumb in model building of no more than one variable per ten events then the model is limited to only four variables within our adjusted models (12). However, this rule of thumb can be relaxed in order to assess relevant confounders (13). It is possible, with a limited ability to adjust on many variables, that the model could have missed potential interactions of variables or possible confounders. Still, recursive partitioning analysis was chosen in an effort to aid in variable selection and this technique allowed for consideration of all available and possibly important variables. The relatively few cases also meant that the analysis may have been underpowered to detect statistical differences in exposures that actually existed. While this study examined five years of data on the two largest cities in Alberta, future studies with larger populations and perhaps a larger sample size could help to improve the precision of estimates and ensure that any differences that do exist are also observed statistically.

The analyses were limited somewhat by sample size within variables as well. The analysis of hospitalized drivers in chapter 4 had a limited number of not-at-fault drivers who were impaired by alcohol (n=4). Although statistically significant differences existed, the small cell size led to wide confidence intervals and therefore a somewhat imprecise estimate. Still, the observed ORs were in line with previous literature (9) and it will always be difficult to establish a large sample of drivers under the influence of alcohol who are not-at-fault in collision. While this is a limitation in the severely injured driver dataset, a more precise estimate of the odds ratio was achieved when applying the tool to a larger sample size that included injuries of different severity.

6.3 External Validity:

A major drawback with the generalizability of our study is that this dataset was restricted to two municipalities. That means that these findings are not generalizable to rural contexts and future studies should examine risk factors for rural youth BMVCs. In addition, the findings presented in this thesis may not necessarily be directly generalizable to other municipalities, potentially due to differences in the built environment, automobile dependence, traffic volumes or population density.

6.4 Causality

Hill proposed cause and effect guidelines that are often used to consider the role of causality. These guidelines include: strength, consistency, specificity, temporality, biological gradient, plausibility, coherence, experimental evidence, and analogy (14).

In the context of these studies, and in particular chapters 3 and 5, the strength of our observed ORs may not be considered extremely strong since these statistically significant increased ORs were usually below 2.0 and for ORs indicating a protective effect near 1 (greater than 0.9) for some variables. A strong association may indicate that there is perhaps less likelihood of an external factor or unmeasured confounder that is influencing the results (15). As previously mentioned, many of our results are consistent with other literature. It is noted that older drivers had higher odds of youth BMVC which is in line with other studies, as was peak rush hour time (16,17). Statistically significant results for sex and severe youth bicyclist injury were not observed nor did the analysis identify alcohol consumption as a statistically significant risk factor. However, the magnitude and direction of these results were in line with previous studies; this builds on the notion that consistency does not always have to include statistically significant results, as this significance or ability to detect differences may vary across studies. Temporality is intact for these studies since it is unlikely, for example, that a collision occurred thereby causing a sign to be present or road type to change; these factors would be present prior to the event. Biological gradient plays a role in our adaptation of the CCST insofar as higher BAC was associated with a higher OR than a lower BAC for causing collision and that a lower, but non-zero, BAC had a higher OR than no drinking. This dose-response has been established in previous literature, but this observation is important for our adaptation in terms of the ability of our tool to assign fault. Plausibility can be influenced by what is already known about the subject (or what is not yet known) (15). However, the consistency of results ties into what is plausible (i.e., older age of drivers) and the results that we observed such as sign presence reducing odds of severe collision are plausible given that signs should warn drivers to slow their speed or to be more vigilant.

It is difficult to say with certainty that our results are causal, especially since BMVCs are complex in nature and may be due to multiple factors working synergistically to produce the event. Our results are helpful in identifying potentially key factors to determining the cause of youth BMVCs that should be considered in future research.

6.5 Future Directions

This thesis identifies a number of future directions including the use of objective and automated culpability analysis tools in a context beyond MV collision cause. The adaptation and automation of this tool in Alberta presents an opportunity for other provinces, municipalities or even countries to also adapt validated measures of culpability in an effort to improve traffic safety research. While the use of this tool in the context of youth BMVCs is novel, we were met with limitations described above. Future studies should address the limitations described, in particular, combining police collision data with other datasets could help to add a level of granularity to the analysis absent from our study. For example, retrospective geographic information system data could help to describe traffic calming interventions or built environment features that may be playing a role in youth BMVCs.

The use of police collision report data in Alberta is an example of administrative data being used for research purposes. This work will be useful in the future as police collision reports are iteratively improved and the use for research purposes will be considered in those improvements. For example, while police collision reports include dozens of important variables, these variables are MV-MV focused. While MV-MV collisions represent the most common type of collision, it is sometimes difficult to understand the characteristics of BMVCs when the form does not allow flexibility to consider bicyclist or other road user factors.

This dataset is unable to establish rates of collision in risk factor categories since there were no data available for bicycle-kilometers travelled; future research should seek to establish a bicycle-kilometers travelled in youth as a measure of exposure and in an effort to establish an accurate rate of youth BMVC. Technological advances and availability may offer an opportunity to measure bicycling trips on a larger scale than in previous research, but more work in this area is needed. This may be important to our findings to understand if certain bicyclist factors are individually risk factors or simply due to greater exposure to roadways.

The culpability tool employed in this research is only used for MV-MV collisions. Future research should seek to develop rules for assigning fault in BMVCs and pedestrian-MV collisions in an effort to create a culpability analysis tool that could identify risk factors for causing these types of collisions. As well, a culpability tool that could assign fault in these bicycle collisions may allow researchers to work with an induced exposure type of analysis in collisions rather than having to measure bicycle-kilometers travelled per year.

Last, this thesis addresses the role of motorists in these collisions. Future research should acknowledge the involvement of MV drivers in potentially causing youth BMVCs. We hope that future studies will expand their focus from the characteristics of the youth bicyclists to continue to include motorist and BE characteristics. Factors for both driver and environment that may contribute to BMVCs and severe injury of youth bicyclists (e.g. driver age, vehicle type, time of day, signage and road type) were observed. In this context, it is imperative that future studies acknowledge the role, or potential role, that motorist and environment factors are playing in youth BMVCs. While we tend to focus on behaviours that youth can modify (i.e., wearing reflectors, wearing a helmet) (17, 18), motorists have equal, or arguably more, responsibility in avoiding collision, especially in the case of youth on the road. Furthermore, given that these collisions occur in environments that are built by society, there is an implicit responsibility to ensure that the design of these environments does not lead to BMVCs or injury.

6.6 Conclusion

Sedentary behaviour remains a public health concern. Efforts to encourage physical activity in a way that is easily accessible and integrated into daily life can be a powerful tool to improve the overall health of the population. This thesis has proposed bicycling in youth as a possible form of physical activity that could be used in daily life that offers a number of physical, social and environmental benefits.

The prevalence and potentially devastating effects of youth BMVCs are a deterrent to youth engaging in this form of physical activity. This thesis takes a novel approach to identify risk factors for youth BMVCs and in doing so contributes to research that can aid in the creation of primary injury prevention strategies.

This research contributes to the youth BMVC literature and identifies risk factors for severe collisions, with the significant risk factors being primarily associated with the environment of the collision. This research also shows that it is possible to adapt and automate validated measures of culpability thus reducing the bias implicit in police assessment or driver infraction assessment of fault. In adapting this tool, and if given access to police report data, other jurisdictions could follow this methodology and improve their ability to determine risk factors for MV collisions. What is more, this tool was then applied to consider risk factors in youth BMVCs. This research not only adds to the gap in literature regarding motorist risk factors for youth BMVCs, but also encourages the use of culpability analysis and QIE principles in non-traditional forms. This thesis identifies differences in odds of being involved in a youth BMVC relative to the typical driving population for older drivers and among vehicle types; future research should consider these variables when examining youth BMVCs. Environmental factors contributing to hospitalization of youth after BMVC were also identified; future research should consider what environmental factors in particular are reducing the severity of collision and how these can be integrated into street design.

Environments that encourage physical activity and reduce injury can have enormous public health benefits. By continuing to identify risk factors for BMVC related injuries in youth we can develop primary prevention strategies that will reduce a leading cause of injury in this vulnerable group, improve overall PA levels, social cohesion and reduce vehicle emissions.

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APPENDIX A. EXAMPLE OF ALBERTA POLICE TRAFFIC COLLISION REPORT DATA FIELDS

ALBERTA COLLISION REPORT FORM - TSS284/TSS284A CODE DEFINITIONS

(Please note that throughout the code 97 identifies missing information)

OCCURRENCE TIME

24 hr clock

COLLISION SEVERITY

01 = Fatal
02 = Injury
03 = Property Damage

HIT AND RUN

01 = Yes
02 = No

PRIMARY EVENT

01 = Struck Object
02 = Off Road Left
03 = Right Angle
04 = Passing - Left Turn
05 = Left Turn - Across Path
06 = Sideswipe
07 = Other
08 = Rear End
09 = Off Road Right
10 = Head On
11 = Passing Right Turn
12 = Sideswipe - Same Direction
13 = Backing

SPECIAL FACILITY

01 = N/A
02 = Interchange Ramp
03 = Interchange Loop
04 = Bridge/Overpass
05 = Tunnel/Underpass
06 = Private Driveway
07 = Traffic Circle
08 = Service Road
09 = Parking Lot
10 = Divided Highway Crossover

ROAD ALIGNMENT A

1 = Level
2 = Grade
3 = Hillcrest
4 = Sag (Bottom of Hill)
9 = Unknown

ROAD ALIGNMENT B

1 = Straight
2 = Curve
9 = Unknown

ROAD CLASS

01 = Undivided One-Way
02 = Undivided Two-Way
03 = Divided With Barrier
04 = Divided No Barrier

08 = Other/Specify

COLLISION LOCATION

01 = Non-Intersection
02 = Intersection Related
03 = At/Near Rail Road Crossing
08 = Other/Specify
09 = Unknown

OBJECT TYPE

01 = Driver
02 = Pedestrian
03 = Motorcyclist
04 = Bicyclist
05 = Parked Vehicle
06 = Train
07 = Animal
08 = Other Vehicle
09 = Other Property

OBJECT ID

01 = Passenger Car
02 = Pick-Up/Van<4500kg.
03 = Mini-Van/Mpv
04 = Truck>4500kg.
05 = Truck Tractor
06 = Motorcycle/Scooter
07 = Pedestrian
08 = Bicycle
09 = School Bus
10 = Transit Bus
11 = Intercity Bus
12 = Other Bus
13 = Fixed Object
14 = Train
15 = Animal
16 = Motorhome
17 = Construction Equipment
18 = Emergency Vehicle
19 = Farm Equipment
20 = Off-Highway Vehicle
21 = Motorized Snow Vehicle
22 = Moped
98 = Other
99 = Unknown

POINT OF IMPACT

01 = Right Front
02 = Right Centre
03 = Right Rear
04 = Back Centre
05 = Left Rear
06 = Left Centre
07 = Left Front
08 = Front Centre
09 = Top
10 = Undercarriage
11 = Rollover
12 = Attachment
97 = Blank
98 = Other
99 = Unknown

DRIVER ACTION*

01 = Driving Properly
02 = Stop sign violation
03 = Yield sign violation
04 = Fail to yield right-of-way uncontrolled intersection
05 = Fail to yield right-of-way pedestrian
06 = Followed too closely
07 = Parked vehicle
08 = Backed unsafely
09 = Left turn across path

10 = Improper lane change	15 = Improper passing
11 = Disobey traffic signal	97 = Blank
12 = Ran off road	98 = Other
13 = Improper turn	99 = Unknown
14 = Left of centre	

*Some of the variables (such as driver action) should only be analyzed in relation to the object type and/or object identification. For example, an object type of 'animal' or 'parked vehicle' will not have a driver action or driver/pedestrian condition associated with it.

LIGHT CONDITION A - NATURAL LIGHT

01 = Daylight	03 = Darkness
02 = Sunglare	99 = Unknown

LIGHT CONDITION B - ARTIFICIAL LIGHT

01 = No Artificial Light	99 = Unknown
02 = Artificial Light	

TRAFFIC CONTROL DEVICE PRESENT

01 = None Present	07 = School Bus
02 = Traffic Signals/Lights	08 = Lane Control Signal
03 = Stop Sign	09 = Railway Crossing
04 = Yield Sign	97 = Blank
05 = Merge Sign	98 = Other
06 = Pedestrian Cross-Walk	99 = Unknown

TRAFFIC CONTROL DEVICE CONDITION

01 = Functioning	04 = Missing
02 = Not Functioning	98 = Other
03 = Obscured	99 = Unknown

PEDESTRIAN ACTION

01 = Xing with Right of Way	04 = Getting On/Off Vehicle
02 = Xing without Right of Way	98 = Other
03 = Walking/Working on Road	

DRIVER/PEDESTRIAN CONDITION

01 = Apparently Normal	05 = Fatigued/Asleep
02 = Had Been Drinking	06 = Medical Defect
03 = Impaired by Alcohol	98 = Other
04 = Impaired by Drugs	99 = Unknown

CONTRIBUTING ROAD CONDITION

01 = No Unusual Condition	02 = Construction/Maintenance

03 = Holes/Bumps/Ruts
04 = Slippery When Wet
05 = Oily Pavement
06 = Soft/Sharp shoulder
98 = Other
99 = Unknown

ENVIRONMENTAL CONDITION

01 = Clear
02 = Raining
03 = Hail/Sleet
04 = Snow
05 = Fog/Smog/Smoke/Dust
06 = High Wind
98 = Other
99 = Unknown

SURFACE CONDITION

01 = Dry
02 = Wet
03 = Slush/Snow/Ice
04 = Loose Surface Material
05 = Muddy
98 = Other
99 = Unknown

LOAD DETAILS A

01 = Loaded
02 = Unloaded
99 = Unknown

LOAD DETAILS B

01 = Load Not Spilled
02 = Load Spilled
99 = Unknown

ATTACHMENT

01 = Large Single Trailer
02 = Large Double Trailer
03 = Large Triple Trailer
04 = Recreation Trailer
05 = Small Utility Trailer
06 = Farm Equipment
07 = Towed Motor Vehicle
08 = Oversize with Pilot
09 = Oversize without Pilot
98 = Other

TRAILER TYPE (IF ATTACHMENT CODED AS 01, 02 , 03)

01 = Van/Box Body
02 = Lowboy
03 = Highboy
04 = Tanker
05 = Dump
06 = Car Carrier
07 = Livestock Carrier
08 = Log Carrier
98 = Other

VEHICLE CONDITION / CONTRIBUTING FACTORS

01 = No Apparent Defect
02 = Defective Brakes
03 = Tires Failed
04 = Improper Load/Shift
05 = Lighting Defect
98 = Other
99 = Unknown

UNSAFE SPEED**

01 = Yes
02 = No
99 = Unknown or N/A

** Applies when the speed was too great under the given conditions (e.g., road, weather and light conditions, traffic density, etc.). Whether or not the driver exceeded a legal speed limit is irrelevant.

POSITION IN VEHICLE

01 = Driver
02 = Passenger
03 = Passenger
04 = Passenger
05 = Passenger
06 = Passenger
07 = Passenger
08 = Passenger
09 = Passenger
10 = Motorcyclist
11 = Bicyclist
12 = Pedestrian
98 = Other
99 = Unknown

SAFETY EQUIPMENT

01 = Lap Belt Only
02 = Lap/Shoulder Belt Assembly
03 = Shoulder Belt Only
04 = Lap/Shoulder with Air Bag
05 = Airbag
06 = Child Safety/Booster Seat
07 = Helmet
08 = None
98 = Other
99 = Unknown

INJURY SEVERITY

01 = None
02 = Minor Injury
03 = Major Injury
04 = Fatal

APPENDIX B. MAPPING OF ALBERTA POLICE TRAFFIC COLLISION REPORT DATA TO CCST

Culpability Scoring Tool Item			Score	Alberta Traffic Collision Report Item
(1) Road Type				
One-way traffic				Road class= Undivided one-way
	Road class = anything other than ramp		1	And Collision location Non-intersection intersection/intersection-related at/near RR crossing
	Road class = ramp		2	And Special facility Interchange ramp OR Collision location Other/specify
Two-way traffic				Road class undivided two-way divided with barrier divided no barrier
	Between intersection		2	And Collision location non-intersection
	At intersection		3	And Collision location intersection/intersection related
	Ramp		3	And Special facility interchange ramp OR Collision location other/specify
	Police list roadside hazard or poor design as contributory factor		5	Contributing road condition= Any condition that is not “normal” Codes= 02-06 & 98/99 98) other/specify
(2) Driving condition = road surface and visibility/weather conditions				
Road surface				Surface Condition and Contributing Road condition

	Dry road/asphalt or concrete		1	Dry/No unusual condition
	Dry road/gravel, oiled gravel, brick, stone, earth, or wood		2	Dry/Loose surface material, oily pavement, other/specify
	Wet road/asphalt or concrete		2	Wet/no unusual condition
	Wet road/gravel, oiled gravel, brick, stone, earth, or wood		3	Wet/Loose surface material, slippery when wet, oily pavement, other/specify
	Road muddy or covered with snow or slush or ice		4	Muddy, slush/snow/ice
	Road surface listed as contributory factor		5	Construction/Maintenance, Holes/Bumps/Ruts, slippery When Wet, Oily Pavement, Soft/Sharp Shoulder
Visibility and weather				Environmental condition and light conditions
	Weather = clear or cloudy		1	Environmental Conditions= clear
			2	Light condition A= Darkness Light Condition B= Artificial Light
	Weather = raining, smog or smoke, or strong wind		2	Environmental Condition= Raining or Smoke/Smog or High Wind.
			3	Light condition A= Darkness

				Light Condition B= Artificial Light
	Weather = snow, sleet, hail, fog		3	Environmental Condition= Snow or Hail/Sleet or Fog
			4	Light condition A= Darkness Light Condition B= Artificial Light
	Police list visibility or weather as a contributory factor		5	Light Condition A= Sun glare
(3) Vehicle condition				
	Vehicle condition not listed as contributory factor in crash		1	Vehicle Condition= No apparent defect
	Police list vehicle condition as contributory factor in crash		5	Vehicle Condition= Defective Brakes, Tires Failed, Improper Load/Shift, Lighting Defect
(4) Unsafe driving actions				Driver Action and/or Unsafe speed
	Driver not obeying road laws or driving in unsafe manner		1	Driver action= Any other driver actions that were not "Driving Properly" Or Speed= unsafe speed
	Driver obeying road laws and driving safely		5	Driver action= Driving properly
(5) Contribution from other parties				
	No contribution		1	Combination of Primary Event, Impact Location,

	from other parties			Collision Description and Driver Action for each collision.
	Contribution from other parties		5	
(6) Type of collision				
Unsafe driving (factor 4)			1	Driver action items 02-98 and/or unsafe speed
No unsafe driving				
	Single vehicle without pedestrian		1	Driver #1 and only one vehicle involved
	Multivehicle crash			
	"Innocent third party"		5	
		Stopped/parked		Collision Description/Impact Location/Driver action=Parked
		Lead vehicle in rear-end collision		Impact Location (Rear) and Impact location of striking vehicle (Front) and Primary Event.
		Third or subsequent vehicle in crash (entity # ≥3– this only applies to crashes with more than 2 vehicles)		Object ID
	Loss of control prior to crash			
		Precollision action = swerving, spinning, yaw, jackknifing, skidding	1	Collision Description

	Maneuvering Vehicle/Pre-collision Action		*	Maneuvering vehicles and pre-collision actions determined using combinations of Primary Event and Impact Locations. Scores will vary depending on these combinations
(7) Task involved				
	Unsafe driving (Factor 4)		1	Driver action= Anything other than “Driving Properly” or “Parked”
	No unsafe driving			
		Avoiding object on road	5	Collision Description
		Parked, stopped in traffic	5	Driver action= Parked Collision Description “Stopped”
		Turning and backing	2	Driver Action= Driving properly Primary Event= Backing, Left Turn Across Path, Passing Left Turn, Passing Right Turn
		All other pre-collision actions	1	

APPENDIX C. RESULTS COMPARING DIFFERENT CULPABILITY CUT-POINTS

```
. logit culp01 i.alcol if mvdriver==1, or

Iteration 0:   log likelihood = -324909.76
Iteration 1:   log likelihood = -321583.19
Iteration 2:   log likelihood = -321506.13
Iteration 3:   log likelihood = -321499.05
Iteration 4:   log likelihood = -321499.04

Logistic regression                               Number of obs   =     471148
                                                  LR chi2(2)      =    6821.45
                                                  Prob > chi2     =     0.0000
Log likelihood = -321499.04                       Pseudo R2       =     0.0105

------------------------------------------------------------------------------
      culp01 | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       alcol |
          1  |   8.535852   .5179003    35.34   0.000     7.578818    9.613737
          2  |   31.41233   2.827198    38.30   0.000     26.33235    37.47233
             |
       _cons |   1.150808   .0033902    47.68   0.000     1.144183    1.157472
------------------------------------------------------------------------------

. logit control1 i.alcol if mvdriver==1, or

Iteration 0:   log likelihood = -192934.62
Iteration 1:   log likelihood = -191274.45
Iteration 2:   log likelihood = -191218.05
Iteration 3:   log likelihood =  -191215.3
Iteration 4:   log likelihood =  -191215.3

Logistic regression                               Number of obs   =     338790
                                                  LR chi2(2)      =    3438.64
                                                  Prob > chi2     =     0.0000
Log likelihood =  -191215.3                       Pseudo R2       =     0.0089

------------------------------------------------------------------------------
    control1 | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       alcol |
          1  |   9.928738   .9916257    22.98   0.000     8.163585    12.07556
          2  |   32.91328   4.728911    24.32   0.000     24.83546    43.61843
             |
       _cons |   2.816222   .0111283   262.03   0.000     2.794495    2.838118
------------------------------------------------------------------------------

. logit control2 i.alcol if mvdriver==1, or

Iteration 0:   log likelihood = -201972.91
Iteration 1:   log likelihood = -200223.13
Iteration 2:   log likelihood =  -200157.8
Iteration 3:   log likelihood = -200153.65
Iteration 4:   log likelihood = -200153.64

Logistic regression                               Number of obs   =     345575
                                                  LR chi2(2)      =    3638.54
                                                  Prob > chi2     =     0.0000
Log likelihood = -200153.64                       Pseudo R2       =     0.0090
```

```
------------------------------------------------------------------------------
    control2 | Odds Ratio   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       alcol |
          1  |   8.007181   .6958836    23.94   0.000     6.753111    9.494135
          2  |   42.38647   6.650437    23.88   0.000     31.16547    57.64754
             |
       _cons |   2.612762   .0100454   249.80   0.000     2.593148    2.632525
------------------------------------------------------------------------------

//Note: culp01=standard cut points
//Note: control1= comparing non-culpable with culpability score 16-21
//Note: control1= comparing non-culpable with culpability score 22-35
//Note: 21 chosen as split point because it is approximately half the culpable
drivers.
```