UNIVERSITY OF CALGARY

ENVIRONMENTAL DETERMINANTS OF BICYCLING INJURIES

by

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Abstract

Bicycling, a popular form of recreation and transportation is associated with positive physical and mental health benefits. While bicycle injuries are common, limited evidence regarding environmental risk factors for bicycling injury exists.

This study examined whether characteristics of the natural and built environment (e.g., traffic, land use, path and aesthetic features) were associated with bicycle motor-vehicle collisions and severe bicyclist injury.

Information on injury circumstances was collected from bicyclists in the emergency department, and environmental audits were conducted at injury locations.

We visited 274 locations, including 42 motor-vehicle and 34 severe injury sites. Traffic volume, intersections, path obstructions, and commercial land use significantly increased the odds of motor-vehicle events. Path type, road condition, streetlights, and surveillance were related to severe injury.

Separating bicyclists from motor-vehicles is of primary importance if collisions are to be reduced. Our findings will inform recommendations to city planners and community leaders to improve bicycling safety and accessibility.

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Dedication

This work is dedicated to my mum and dad, for instilling in me the value of knowledge and the importance of education. Thank you for helping me up each rung on the ladder of life, and for offering “free” advice every step of the way.

J’aimerais dédier ma thèse à maman et papa. Merci d’avoir semé en moi l’importance de l’éducation. Sans vos conseils gratuits, je n’aurais pas eu le même succès. Je vous aime!

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"Life is like riding a bicycle – in order to keep your balance, you must keep moving."

–Albert Einstein

Chapter One: Introduction

Bicycling is an easy activity that can be enjoyed by almost anyone around the world. Rates of bicycling vary widely by country; the percentage of all trips made by walking or bicycling is estimated to range from 6% in the United States to 46% in the Netherlands.(**1**) In Canada, it is reported that 60% of adults own or have use of a bicycle (**2**); however, bike ownership does not predict use. While some non-modifiable factors contribute to the variation in bicycling rates such as climate and geography, other factors that encourage or discourage bicycling including the way cities are designed, also influence the number of people who bicycle.

Bicycling is a popular activity for children and families, and learning to ride a bike is one of the most common childhood milestones. Bicycling is also an increasingly common form of transportation. The personal and environmental benefits of bicycling for transportation are well established, and yet, in North America the majority of trips are still made by private car. Many cities are taking steps to encourage people to choose active modes of transportation. It is reported that 83% of Canadians live within a reasonable bicycling distance of at least one routine destination (8km).(**2**) Therefore, there are opportunities to encourage people to choose bicycling by making it safer and more easily accessible as a recreational activity and for transportation.

The benefits of physical activity such as bicycling, are well known and research continues to show that regular physical activity has long term health benefits.(**3, 4**) However, as with any activity, bicycling also carries the risk of injury, and this risk may make some people reluctant to participate. Canadians' bicycle safety concerns are reinforced by injury statistics. Bicycle-related injuries are the most common category of sport and recreation injury death, hospitalization and emergency department (ED) visits for those less than 19 years of age.(**5, 6**) Unfortunately, bicyclists are often involved in collisions with motor-vehicles. These events tend to result in more severe injuries and in some cases death.(**7**) In 2007, 65 Canadian bicyclists were involved in a fatal collision with a motor-vehicle.(**8**)

Injury prevention strategies have focused on encouraging helmet use and establishing helmet legislation. While these initiatives are known to be effective there is limited evidence on other bicycling injury risk factors, especially factors related to the built environment. It is important to examine the natural and built environment for injury risk factors in order to provide recommendations to city planners and community leaders to improve bicycling safety and convenience.

1.1 Purpose

Bicycling is accessible to virtually every citizen without a physical disability and yet information on risk factors for injuries, particularly factors related to the environment remains limited. To reduce the risk of injury and increase the number of bicyclists, evidence on specific environmental risks for injury is necessary. As such, the purpose of this project was to examine the environmental and structural characteristics of high bicycling injury risk locations in Calgary and Edmonton, Alberta, by combining data on injury circumstances with an environmental audit of injury locations.

1.2 Objectives

The specific objectives of this study were; 1) To examine and describe the characteristics of the natural and built environment (i.e., road/path characteristics, natural features, obstacles/obstructions) of bicycling injury risk locations in Calgary and Edmonton, Alberta; 2) To compare the characteristics of locations where bicyclists were struck by a motor-vehicle with those of locations where bicyclists were injured in non-motor-vehicle related incidents; 3) To compare the characteristics of severe injury crash locations with those of non-severe injury crash locations.

1.3 Rationale and Relevance

Regular physical activity such as bicycling has long term health benefits. Further, bicycling is an environmentally friendly, economical mode of transportation. Despite public health initiatives promoting healthy lifestyles and government policies that encourage bicycling as an alternative mode of transportation, many Canadians remain inactive. In addition, the safety risks associated with bicycling are barriers for choosing this activity. While bicycle helmets and legislation have proven to be effective in reducing the risk of a head injury, more research is needed to examine other risk factors for injuries, including factors related to the natural and built environment. By prospectively examining these risk factors, this study will contribute to the field of injury prevention and help to address safety issues by informing policy makers, interest groups, and bicyclists, in hopes of encouraging more people to ride a bike.

1.4 Summary of Thesis Format

In this thesis, I will first introduce the problem of unintentional injuries and then review some of the existing literature on physical activity and bicycling in Canada. I will provide an overview of the evidence on risk factors for bicycling injuries, highlighting the need for more information on how the environment affects bicycling rates and injuries. The literature review will also discuss research that has been conducted on designing walking and bicycling friendly environments (Chapter Two). This will be followed by a detailed description of our matched case-control and environmental audit methodology (Chapter Three). The results of this study will be presented in Chapter Four, followed by a discussion of the findings including the strengths and limitations of the research in Chapter Five. A summary of the findings, implications, and recommendations for improving bicycling safety will be presented in the final chapter (Chapter 6).

Chapter Two: Literature Review

2.1 The Problem of Injury

Unintentional injuries including those related to burns, falls, drowning, poisoning, transportation, sport and recreation, are major causes of disability, morbidity, and mortality worldwide.(**9**) In Canada, injuries are the leading cause of death for those 1 to 44 years of age, and the fourth leading cause of death for Canadians of all ages.(**10**) In 2004, the economic burden of unintentional injuries in Canada was estimated to be $19.8 billion.(**11**)

A large portion of these injuries are road traffic related. Road traffic injuries, including pedestrian and bicyclist injuries, are extremely common and largely preventable. It is estimated that 1.3 million people die each year on the world's roads, and that an additional 20-50 million sustain non-fatal injuries.(**12**) Road traffic injuries are the leading cause of death for those 15-29 years old, and the second leading cause of death for those 5-14 years old worldwide.(**12**) Bicyclists, pedestrians, children, and the elderly are among the most vulnerable of road users and they account for nearly 50% of global road traffic deaths.(**12**) In 2004, a 6-month prospective study of emergency department (ED) presentations by vulnerable road users in Perth, Australia found that bicyclists represented more than half of patients.(**13**) In Canada, bicycling injuries are the fourth leading cause of unintentional injury-related hospitalizations for those 0-14 years old.(**14**) This represents a significant cost to the health care system; estimates from the United States have found that the annual cost of bicycle injuries and related deaths is $8 billion.(**15**) The economic and personal costs of bicycle injuries is greater when bicyclists are involved in collisions with motor-vehicles, as these events tend to result in more severe injuries. As vulnerable road users, bicyclists are at additional risk when their needs have not been considered during the planning of land use or road design. The safety of these road users can be enhanced by modifying transport infrastructure to make these systems more accommodating for multiple modes of transportation.

Some areas have taken important steps to create environments that are conducive to multiple forms of transportation including bicycling and walking, and have been shown to have reduced injury rates among these vulnerable road users. In the Netherlands, Germany, and Denmark, bicycling levels are more than ten times higher than in the United States.(**16**) Yet, injury rates in the U.S. are 5.8 per 100 million kilometres cycled, compared with 1.7 in Germany, 1.5 in Denmark, and 1.1 in the Netherlands.(**16**) Other evidence suggests a “safety in numbers” effect where injury rates among bicyclists and pedestrians are found to be lower in areas with more bicyclists and pedestrians.(**17**) However, this suggestion should be interpreted with caution, as some of the decreased risk in these areas may be related to features that make the areas safer to begin with. Regardless, these findings support the idea that by modifying the environment and encouraging more people to bicycle, injury rates can be reduced.

Unintentional injuries, including bicycle injuries are a global concern. As such, efforts must be made to identify factors that increase the risk of injury for bicyclists. Dramatic geographic differences in injury rates may suggest that potential risk factors exist in the built environment. While there is evidence indicating that the built environment can be designed to successfully accommodate multiple modes of transportation, whether or not specific features of the environment contribute to increased levels of bicycling or injury rates has yet to be determined.

2.2 Inactivity and Obesity

The individual and public health benefits of physical activity such as bicycling for recreation or transportation are numerous. Taking part in regular physical activity lowers the risk of being overweight, thus reducing the likelihood of developing associated health problems. Despite public health initiatives promoting healthy lifestyles, 51% of Canadian adults are inactive.(**18**) Further, 78% of youth ages 12-19 are not physically active enough to meet the international guidelines for optimal growth and development.(**18**) It is well established that sedentary living is directly related to being overweight, which can lead to serious health problems such as type 2 diabetes, cardiovascular, and heart disease.

Obesity rates have steadily increased over the past 20 years. In 1985, 5.6% of Canadian adults were obese; this number increased to 15% in 2001.(**19**) By 2004, 23.1% of adults were obese, while an additional 36.1% of Canadians over 18 years, and 26% of children and adolescents were considered overweight.(**20**) The rising trend of obesity and related illness is not only a problem in developed countries; in fact, the World Health Organization has recognized the obesity epidemic as a worldwide issue in need of immediate action. It is estimated that by 2015 approximately 2.3 billion adults worldwide will be overweight, and an additional 700 million will be obese.(**21**) It is accepted that one of the major contributors to the problem of obesity is the global trend toward decreased levels of physical activity. Rising inactivity is partially driven by the sedentary nature of many modern day occupations, as well as greater reliance on motorized transportation, which in turn is linked to global urbanization.(**21**)

The health problems associated with the obesity epidemic are a burden on the health care system. In the United States alone the estimated cost of treatment for obesity related conditions was estimated to be between $92.6 and $117 billion in 2003, projected to rise annually.(**22**) In 2001, the estimated economic burden of physical inactivity in Canada was $5.3 billion, while the cost associated with obesity was $4.3 million.(**23**)

The magnitude of the obesity epidemic cannot be understated and addressing the trend of inactivity is one method of taking action against this problem. Such initiatives can take many forms, including trying to promote physical activity such as bicycling, by making it more accessible and safe.

2.3 Economic and Health Gains of Bicycling

Evidence suggests that some of the costs associated with inactivity and obesity may be offset by investing in initiatives promoting physical activity such as improved bicycling infrastructure.(**24**) A cost-benefit analysis of walking and bicycling track networks taking into account the benefit of reduced insecurity and the health benefits of improved fitness through the use of non-motorized transport, found that the benefits of investments in bicycle networks were estimated to be at least 4-5 times the costs.(**25**) De Hartog et al. found that on average, the individual health benefits of bicycling were almost 9 times larger than the risks when compared with car driving.(**26**) For society as a whole, the benefits can be even greater if one considers the positive effects of reduced air pollution, traffic congestion, collisions, and related health care costs.

2.4 Bicycling to Stay Active

Bicycling for transportation or recreation is an easy way to integrate physical activity into daily life. Bicycling for commuting is an environmentally friendly choice and municipalities are trying to find ways to encourage people to bicycle to work or other routine destinations.(**26, 27**) An example of such initiatives is the recent implementation of public bike share programs in major cities including Montreal, Paris, and London.(**28**) In Calgary, Alberta, the proportion of people bicycling to work increased by 18% from 1996 to 2006.(**29**) However, the proportion of people bicycling to work is still very low; only 1.3% of Canadians bicycled to work in 2006.(**29**) Active commuting is an easy way of accumulating the recommended daily amount of physical activity. Indeed, bicycling to work has been shown to decrease the risk of all-cause mortality by up to 40%, even when controlling for other types of leisure physical activity.(**3**)

Bicycling for recreation is a popular activity for children and families and many areas have developed bicycle or multi-use pathways to encourage riding. Ninety-one percent of Canadian children aged 5-12 years and 77% of those 13-17 years reported having ridden a bike in the past year.(**30**) Despite this, a recent report noted that less than 2% of children reported using a bike for active commuting, such as riding to school.(**31**) In fact, while there is evidence that the proportion of adults choosing to bicycle to commute is increasing, the opposite may be true for children.(**2, 29**)

As evidence shows that more than half of Canadian adults are not meeting the recommended guidelines for physical activity and that nearly 80% of children may be at risk of developmental setbacks related to inactivity (**18**), finding ways to encourage safe, regular physical activity is crucial.

2.5 Barriers to Bicycling

Many individual and population level factors must be considered when trying to find ways to encourage people to bicycle. Studies have shown that there is a positive correlation between the number of facilities that are provided and the percentage of people that use bicycling for commuting purposes.(**32, 33**) Traffic and safety concerns are stated as important barriers to active commuting.(**34**) The main issues preventing Canadians from choosing bicycling for transportation more often than they do are weather (29%), followed by distance or environment (28%), safety in traffic, storage or security (17%), time (15%) and practicality (11%).(**2**) Of those surveyed in the 2004 National Transportation Survey, 69% stated that increased safety in traffic would assist them to bicycle more.(**2**) Other safety interventions identified as important by those surveyed were designated or better designed bicycling lanes on roadways, laneways to key locations in the community, and better lighting on pathways.(**2**) In Calgary, a public survey found that 64% of respondents felt unsafe when bicycling in traffic. Additionally, more people would be willing to commute by bike if dedicated bike lanes were present, particularly in the congested downtown core.(**35**) In Vancouver, a study on motivators and deterrents of bicycling among both current and "would be" bicyclists identified that the main motivators for both groups were routes away from traffic, aesthetic appeal, and ease of activity (i.e., difficulty of the route). On the other hand, the strongest deterrents were unsafe surfaces and interactions with motor-vehicles. When individual motivators and deterrents were grouped into categories, the strongest positive influences on choosing to bicycle were safety aspects, ease of bicycling, and route and weather conditions.(**36**) Others have found that bicycling is positively associated with the presence of bike lane connectivity, and that people would be willing to accept a longer travel time if it meant having access to on-road designated bike lanes.(**37, 38**)

It is important to recognize that nearly all the factors mentioned as barriers to bicycling are modifiable; yet while these factors are suggested to encourage more people to bicycle, there is little evidence of their impact on safety or the risk of injury.

2.6 Bicycling Injury Risk Factors

Research has identified several individual level risk factors for bicycling injuries, including age, sex, helmet use, and the choice of bicycling location (e.g., roadway vs. non-roadway). The following sections highlight studies that have contributed to this body of knowledge. It is important to note that many of the studies conducted on the epidemiology of bicycling injuries have been case-series analyses using various types of data sources including ED records, police records, and fatality data. Unfortunately the nature of these studies makes it challenging to estimate measures of association between independent variables and injury, as minimal information is available on the source population of exposure. Nevertheless, some studies have mitigated this limitation by using population based estimates or more rigorous study designs.

2.6.1 Age

Age has consistently been identified as a risk factor for bicycling injuries and it is apparent that children are disproportionately affected. In the United States, it is estimated that there are over 500,000 ED visits annually for bicycle-related injuries, over 300 000 of which involve patients under 18 years of age.(**39, 40**) In Canada, bicycle injuries are the most common category of sport and recreation injury deaths, hospitalizations and ED visits for those less than 19 years of age.(**5**)

According to Alberta Transportation data, there were 549 bicyclists injured and 5 killed on Alberta roadways in 2008.(**41**) Bicyclists 10-14 years old had the highest injury rate at 3.7 per 10,000 population, followed by those 15-19 years old at 3.3 injuries per 10,000 population.(**42**) The 10-14 year age group has consistently been found to have higher injury rates.(**15, 39, 40, 43**) Some, if not most of the increased rate in children likely reflects the greater amount of time spent bicycling among these age groups (e.g., increased exposure to risk). A higher rate in younger age groups increases the burden of injury on families and communities. Parents of injured children may need to stay home to provide care, and children may not be able to participate in regular activities. Further, children who suffer severe head or brain injuries as a result of a bicycling crash may have impaired development and functioning and require a higher level of care. Bicycling fatalities tend to occur in previously healthy children and adults, and result in an important increase in the number of years of productive life lost.(**44**)

In a prospective case-series study, Ortega, Shields, and Smith examined paediatric ED records and interviewed parents of injured bicyclists. They found that children 7 years or older had a higher risk of being involved in a collision with an object, motor-vehicle, or person, compared with younger children (relative risk [RR] 1.19, 95% confidence interval [CI] 1.15-1.27).(**45**) Another similar retrospective case-series study in the United States found that those 15-18 years old had four times the risk of being involved in a fatal event compared with those less than 15 years old (RR 3.93, 95% CI 1.63-9.46).(**40**) This is likely a reflection of the fact that adolescents may choose to ride on the road more often than younger children, and thus have a higher exposure to motorized and other non-motorized vehicles.

In a case-control study, Rivara et al. examined bicycling ED presentations for evidence on risk factors for severe injuries.(**7**) The study found that severe injury risk was related to being younger than 6 years (odds ratio [OR] 1.6, 95% CI 1.1-2.4), and older than 39 years (OR 2.2, 95% CI 1.4-3.5). Those 6-19 years of age did not have significantly higher odds of severe injury in comparison with the reference category of 20-39 year olds. The fact that this study found an association between younger and older age groups (compared with the aforementioned research) and severe injury may be a reflection of the fact that the Rivara et al. study relied on data from several adult and paediatric EDs, while the studies previously mentioned focused on paediatric patients, using nationally representative samples from existing databases. The differences in the age distribution of injured bicyclists in the three studies may account for the discrepancy in results. Other all age studies have also identified older age groups (>55 years) as having a higher risk of injury.(**43, 46**)

It has been demonstrated that there is a relationship between bicyclist age and injuries. While children 10-14 years old have consistently been found to have the highest injury rates, varying age categories have been shown to have a greater risk of severe injury or death depending on the population source used.

2.6.2 Sex

In the bicycling injury literature, the proportion of injured who are males is consistently greater than females.(**15, 39, 40, 44, 47**) This is likely a reflection of the fact that more bicyclists are males. Moreover, there is evidence that males have a higher risk of injury compared with females. Rowe et al. studied provincial coroner's reports on fatal bicycle-related trauma in Ontario, Canada between 1986 and 1991 and found that fatal crash victims were more likely to be men and to be riding without a helmet.(**44**) As well, the study by Rivara et al. found that being a male was a significant risk factor for hospital admission. Conversely, a retrospective case-series study in the Czech Republic found that being female had a protective effect on the risk of suffering a fatal injury when involved in a collision with a motor-vehicle (OR 0.55, 95% CI 0.46-0.66).(**7**)

The evidence that males have a greater risk of injury is mirrored in other sports and recreation activities. One possible explanation that has been supported is that males have a higher risk taking propensity. Where bicycle injuries are concerned, an example of this is that males have been found to be less likely to wear a helmet.(**48, 49**)

2.6.3 Helmet Use

Much of the bicycling injury prevention literature has focused on helmet effectiveness and helmet legislation. For example, two systematic reviews demonstrated that helmets reduced the risk of a head, brain, and severe brain injury under a variety of crash circumstances and in all ages of riders.(**50, 51**) Similarly, systematic reviews have been conducted examining the evidence on the effect of helmet legislation, and showed that rates of head injuries were reduced and helmet use increased in populations where helmet use was mandated.(**52, 53**) Despite the positive effects of helmet wearing and legislation, in Alberta, only 53% of bicyclists under the age of 18, and 48% of those over 18 were reported to be wearing a helmet.(**54**) Among the 30 fatally injured bicyclists in Alberta in 2004-2008, only 37% were wearing a helmet.(**41**) Bicycling injuries remain a major concern and helmet use alone is not enough to prevent them.

2.6.4 Motor-Vehicle Collisions

Injury events involving motor-vehicles are more likely to result in hospitalization, severe injury, or death, regardless of the bicyclist's age.(**7, 40, 43, 44, 47, 55**) In their case-control study, Rivara et al. noted that severe injury was related to being struck by a motor-vehicle (OR 4.6, 95% CI 3.3-6.3).(**7**) In their study on fatal bicycle trauma, Rowe at al. found that collision with a motor-vehicle was the cause of death in 91% of cases.(**44**)

A few studies have used police report data to examine specific factors in bicycle vs. motor-vehicle incidents that may increase the risk of injury for bicyclists. A retrospective study of police traffic collision reports conducted in the Czech Republic found that the odds of death for a bicyclist were 8.27 (95% CI 5.78-11.82) times as great when the motorist was at fault and was speeding, compared to the most frequent type of collision, when a bicyclist was denied the right of way.(**56**) A similar American study revealed the following factors increased the probability of death in bicycle motor-vehicle collisions: vehicle speed above 32.2 km/hr, impact with a heavy truck, and intoxicated bicyclists/drivers.(**46**)

Local data from Alberta Transportation for 2004-2008 suggest that 98% of bicycling injuries and deaths occurred in urban areas and that an intersection-related traffic control device was present at 34% of the events. Almost two thirds (63%) of bicyclists involved in a motor-vehicle collision made an improper action whereas over 40% of the drivers of other vehicles involved in the collision committed an error that contributed to the crash.(**41**)

Clearly, being involved in a collision with motor-vehicle increases the risk of suffering a severe injury. Since sharing the road with motorists is often the only option for bicyclists, some factors in the roadway environment may be modified to mitigate the risk of injury, such as vehicle speed. Other modifiable factors that could influence the risk of being struck by a motor-vehicle still need to be examined, including roadway width, presence of designated bicycle lanes, and traffic volume.

2.6.5 Time of Day

Light conditions and visibility are likely to influence the risk of a bicyclist crashing or being struck by a motor-vehicle. In a study of paediatric ED visits, Ortega, Shields, and Smith found that most injury events (84%) occurred from April to September, between the hours of 13:00-21:00 (88%).(**45**) In the study by Rowe et al., the majority (69%) of crashes occurred during daylight hours from 08:00 to 20:00; however, 15% occurred between midnight and 08:00.(**44**) This important proportion of late night events may suggest that other confounding factors, such as the use of alcohol, may have increased the risk of injury at the time.

The Czech study previously mentioned included a measure of the effect of different light conditions on the risk of serious injury or death. The findings indicated that compared with daytime conditions, the odds of death increased when collisions occurred after sunset (OR 1.4, 95% CI 1.08-1.8), and in locations without streetlights (OR 2.16, 95% CI 1.75-2.67).(**56**) In a study by Kim at al. the probability of death for bicyclists increased when collisions occurred prior to 10:00.(**46**) The fact that risk of fatality by time of event differed in the two aforementioned studies may be because the Czech study was limited to adult bicyclists and that the inclusion of children (Kim et al.) might increase the number of morning events when children are more likely to bicycle (e.g., bicycling to school).

Better street lighting has been proposed as a method of making bicycling safer.(**57**) Improved lighting can make bicyclists more at ease and easier to see for motorists, pedestrians, and even other bicyclists. It is important to consider this particularly in the Canadian context where winter conditions reduce the amount of daylight. Those choosing to bicycle to and from work often commute in the dark, placing them at a greater risk of injury. It is also important to encourage the use of visibility aids among bicyclists, such as bicycle reflectors, retro-reflective clothing, and lights.

2.6.6 Other Risk Factors

While evidence of the effect of visibility aid use on bicyclist injury outcomes is limited, it has been suggested that motorist detection of pedestrians and bicyclists increases when these groups use fluorescent colours.(**58**) Recent evidence suggests an association between wearing fluorescent colours and a lower number of days off work after an injury resulting from a bicycle crash.(**59**) Despite this, visibility aid use has been documented as being low.(**60, 61**) This is an area that needs further examination, particularly given that bicycling in poor light conditions is a known risk factor for serious injury.

Several studies have examined the effect of alcohol use on bicycling injuries. Using a matched case-control design, Li et al. found that among bicyclist over the age of 15, the adjusted OR of bicycling injury for those with a blood alcohol level of 0.08 g/dl or higher was 20.2 (95% CI 4.2-96.3).(**62**) In a prospective case-series study of injured bicyclists presenting to an ED in Texas, alcohol use increased the risk of suffering a head or brain injury three-fold (OR 3.63, 95% CI 1.57-6.63).(**63**) Bicyclists who had consumed alcohol were also more likely to be bicycling late at night, in poor road conditions, and on a street (vs. an off-road path, trail, or highway).(**63**) In both studies the investigators noted an association between alcohol use and wearing a helmet.(**62, 63**)

Another individual risk factor for bicycling injuries is bicyclist speed. While this factor has not been closely examined, Rivara et al. noted that crashes that occurred at a speed above 15 mph had a 20% increase in the risk of severe injury.(**7**) This finding may support the presence of posted speed limits on bicycle tracks or pathways.

2.6.7 Non-roadway Incidents

Roadway incidents and those involving motor-vehicles tend to result in more serious injuries; however, an even greater number of bicycling injuries are sustained in non-roadway locations, in single party events. These types of injuries have not received a great deal of attention in bicycling injury research, likely due to the difficulties associated with collecting information on events that did not occur on public roadways, and for which traffic collision reports do not exist. Jacobson, Blizzard, and Dwyer examined ED presentations for bicycling injuries at a hospital in Tasmania during a 4 year period and found that over 62% of injuries occurred at locations other than public roads, such as pathways and driveways, and that 79% did not involve another object, person, or vehicle.(**47**) Other studies have found similar results, highlighting the need to examine the characteristics of non-roadway locations and their potential relationship to injury risk.(**13, 45, 55, 64**)

While individual risk factors for bicycling injury have been examined, there is little evidence on other risk factors such as those in the natural and built environment. There is an emphasis throughout the bicycling literature on the need to further elucidate the relationship between characteristics of the physical environment and injury risk. Table 2.1 presents a summary of the case-series studies on bicycling injuries included in this review. Case-series designs do not lend themselves easily to calculating the effect of individual factors on injury risk, due to limited information on the characteristics of the source population. However, the results of these studies provide a picture of the individual characteristics of injured bicyclists and their crash circumstances. The ensuing Table 2.2 includes studies that have overcome this limitation and lists studies that have presented measures of effect for various risk factors.

Table 2.1 Case-Series Studies on Bicycle Injuries

Study	Design	Sample	Results
Rowe, B.H.; Rowe, A.M.; Bota, G.W. (1995), Ontario, Canada(**44**)	Retrospective case-series	n=212 deceased bicyclists from 1986-1991	78% of victims were males 69% of crashes occurred during daylight hours 15% of crashes occurred between midnight and 8 am 91% of events were collisions with motor-vehicles (m-v)
Jacobson, G.A.; Blizzard, L.; Dwyer, T. (1998), Tasmania, Australia(**47**)	Retrospective case-series	n=599 injured bicyclists treated in an emergency department from 1991-1995	Male:Female ratio 3.5:1 61.6% of events occurred off-road 79.3% of events were single-person events 5.2% of events were on-road collisions with m-v <10 years more likely to be injured off-road compared with adult bicyclists
Stutts, J.C.; Hunter, W.W. (1999), California, New York, N. Carolina, USA (**55**)	Prospective case-series	n=1066 bicyclists treated in one of eight emergency departments between 1995-1996	70% of events did not involve a m-v 31% of events occurred off-road 25% of bicyclists injured in m-v collisions were hospitalized, compared with <10% of those in other event categories (p<0.001) 43% of hospitalizations were not related to a m-v and did not occur on a roadway
Ortega, H.W.; Shields, B.J.; Smith, G.A. (2004), Ohio, USA(**45**)	Retrospective case-series with follow-up interview for hospitalized bicyclists	n=658 injured bicyclists less than 20 years old, treated at an emergency department during a 1 year period	87.5% of injuries occurred between 13:00-21:00 73.1% of events did not occur on a roadway RELATVE RISK OF COLLISION (m-v or other bicycle) 1.0 for <6 years (reference category) 1.19 (95% CI 1.15-1.27) for 7-20 years
Shah, S.; Sinclair, S.A.; Smith, G.A.; Xiang, H. (2007), USA(**15**)	Retrospective case-series	n=6511 bicyclists less than 20 years old hospitalized during 2003	10-13 years old had highest hospitalization rate (23.8/100 000) 76.7% (95% CI 75.6-77.7) male 30% of crashes involved a m-v
Haileysus, T.; Annest, J.L.; Dellinger, A.M.; (2007), USA(**39**)	Retrospective case-series	n=5281 hospitalized bicyclists from 2001-2004	10-14 years old had the highest injury rate (65.8/100 000) 80.7% male 21.5/100 000 (95% CI 14.3-28.7) involved a m-v

Study	Design	Sample	Results
Mehan, T.J.; Gardner, R.; Smith, G.A.; McKenzie, L.B. (2009), USA(**40**)	Retrospective case-series	n=166 403 bicyclists under 18 years of age treated in emergency departments from 1990-2005	10-14 years had the highest injury rates (7.98/ 1000 children) 70.2% male Males 10-14 years had the highest injury rate by age/sex category, 11.67/1000 RELATIVE RISK OF HOSPITALIZATION 1.0 for injury to body region other than head (reference category) 3.63 (95% CI 3.22-4.10) for head injury RELATIVE RISK OF FATALITY 1.0 for injury to body region other than head (reference category) 5.77 (95% CI 2.56-12.98) for head injury 1.0 for <15 years 3.93 (95% CI 1.63-9.46) for 15-18 years
Bil, M.; Bilova, M.; Muller, I. (2010), Czech Republic(**56**)	Retrospective case-series	n=5428 traffic collisions involving adult bicyclists from 1995-2002	FATALITY ODDS RATIO 1.0 for collisions resulting from motorist error and denial of right of way (reference category) 8.27 (95% CI 5.78-11.82) for collisions resulting from motorist error and speeding 1.0 for daytime events (reference category) 1.4 (95% CI 1.08-1.80) for after sunset events 2.16 (95% CI 1.75-2.67) for after sunset without streetlights 1.0 for males (reference category) 0.55 (95% CI 0.46-0.66) for females 1.0 for 18-24 years (reference category) 2.22 (95% 1.63-3.01) for >65 years
Chong, S.; Poulos, R.; Olivier, J.; Watson, W.L.; Grzebieta, R. (2010), New South Wales, Australia (**43**)	Retrospective case-series	n=1610 bicyclist injuries resulting from a collision with a m-v or pedestrian, identified by State mortality and morbidity data	10-14 years old injured in m-v collisions had the highest rate of hospitalization (~3/100,000) SEVERE INJURY ODDS RATIO 1.0 for 10-19 years 2.17 (95% CI 1.16-4.00) for >65 years
Crocker, P.; Zad, O.; Milling, T.; Lawson, K.A. (2010), Texas, USA(**63**)	Prospective case-series	n=200 injured bicyclists >18 years treated at an emergency department over a 1 year period	80.5% male 36% of cases involved a m-v 16% were hospitalized 77% of events occurred on a roadway 24% of events occurred between 20:01 and 05:00

Table 2.2 Individual Risk Factors for Bicycle Injuries

Study	Design	Sample	Outcomes	Risk Factors	Effect Measure
Rivara, F.P.; Thompson, D.C.; Thompson, R.S. (1997), Seattle, USA(**7**)	Prospective case-control	n=3390 bicyclists treated in emergency departments or deceased between 1992-1994	Serious injury as defined by injury severity score (ISS) >8	Motor-vehicle involvement	SERIOUS INJURY ODDS RATIO 1.0 all non m-v crashes (reference category) 4.6 (95% CI 3.3-6.3) for collisions with a m-v
				Speed	1.0 ≤15 mph (reference category) 1.2 (95% CI 1.0-1.5) for speed >15 mph
				Age	1.0 for 20-39 years old (reference category) 2.1 (95% CI 1.2-3.8) for <6 years 2.2 (95% CI 1.4-3.5) for >39 years
Bil, M.; Bilova, M.; Muller, I. (2010), Czech Republic(**56**)	Retrospective case-series	n=5428 traffic collisions involving adult bicyclists from 1995-2002	Fatality	Type of crash	FATALITY ODDS RATIO 1.0 for motorist error and denial of right of way to bicyclist (reference category) 8.27 (95% CI 5.78-11.82) for motorist error and speeding
				Sex	1.0 for males (reference category) 0.55 (95% CI 0.46-0.66) for females
				Age	1.0 for 18-24 years (reference category) 2.22 (95% 1.63-3.01) for >65 years
Ortega, H.W.; Shields, B.J.; Smith, G.A. (2004), Ohio, USA(**45**)	Retrospective case-series with follow-up interview for hospitalized bicyclists	n=658 injured bicyclists less than 20 years old, treated at an emergency department during a 1 year period	Crash circumstances	Age	RELATIVE RISK OF COLLISION (with m-v or other bicycle) 1.0 for ≤6years (reference category) 1.19 (95% CI 1.15-1.27) for 7-20 years
Mehan, T.J.; Gardner, R.; Smith, G.A.; McKenzie, L.B. (2009), USA(**40**)	Retrospective case-series	n=166 403 bicyclists under 18 years of age treated in emergency departments from 1990-2005	Hospitalization or fatality	Age	RELATIVE RISK OF FATALITY 1.0 <15 years old (reference category) 3.93 (95% CI 1.63-9.46) for 15-18 years

Study	Design	Sample	Outcomes	Risk Factors	Effect Measure
Chong, S.; Poulos, R.; Olivier, J.; Watson, W.L.; Grzebieta, R. (2010), New South Wales, Australia(**43**)	Retrospective case-series	n=1610 bicyclist injuries resulting from a collision with a motor-vehicle or pedestrian, identified by State mortality and morbidity data	Injury severity measured by ICD-10-AM codes and ICD derived ISS	Age	SEVERE INJURY ODDS RATIO 1.0 for 10-19 years (reference category) 2.17 (95% CI 1.16-4.00) for >65 years
Kim, J-K.; Kim, S.; Ulfarsson, G.F.; Porello, L.A. (2007), North Carolina, USA(**46**)	Retrospective case-series	n=2934 traffic collision reports involving bicyclists (all ages) from 1997-2002	Four injury severity levels: 1) fatal 2)incapacitating 3) non-incapacitating 4) possible or no injury	Age Alcohol use	FATALITY ODDS RATIO 1.0 <55 years (reference category) 2.17 (95% CI 1.01-4.62) for ≥55 years 1.0 for no alcohol use (reference category) 2.88 (95% CI 1.57-5.27) for alcohol use *Based on my calculations from the authors data. Standard error of the coefficient was used to calculate the 95% CI, therefore limits should be interpreted with caution.
Li, G.; Baker, S.P.; Smialek, J.E.; Soderstrom, C.A. (2001), Maryland, USA(**62**)	Matched case-control	n=124 cases identified through medical records, n=342 controls randomly selected	Bicycle injury and estimated blood alcohol level (BAC)	Alcohol use	INJURY ODDS RATIO 1.0 for BAC <0.02 g/Dl (reference category) 5.6 (95% CI 2.2-14.0) for BAC >0.02 g/dL 20.2 (95% CI 4.2-96.3) for BAC >0.08 g/dL
Crocker, P.; Zad, O.; Milling, T.; Lawson, K.A. (2010), Texas, USA(**63**)	Prospective case-series	n=200 injured bicyclists >18 years treated at an emergency department over a 1 year period	Alcohol use and head/brain injury	Alcohol use	HEAD INJURY ODDS RATIO 1.0 for no alcohol use (reference category) 3.63 (95% CI 1.57-6.63) for alcohol use

Study	Design	Sample	Outcomes	Risk Factors	Effect Measure
Thompson, D.C.; Rivara, F.; Thompson, R.(1999)(**51**)	Systematic review	Five case-control studies	Helmet use, head and facial injuries	Helmet use	HEAD INJURY SUMMARY ODDS RATIO 1.0 no helmet use (reference category) 0.31 (95% CI 0.26-0.37) with helmet use BRAIN INJURY SUMMARY ODDS RATIO 1.0 no helmet use (reference category) 0.31(95%CI 0.23-0.42) with helmet use compared with non-use Overall, 63-88% decrease in risk of head injury with helmet use Overall 65% decrease in risk of upper and mid facial injury with helmet use

2.7 Environmental Risk Factors

Some potential environmental risk factors have been examined, including various bicycling locations (e.g., roadways, sidewalks, and parking lots), bicycling infrastructure (e.g., marked bicycle lanes on roadways, separated bicycle tracks), intersections, and weather/light conditions. The following sections present the evidence to date.

2.7.1 Bicycling Location

In some areas, bicyclists have options when choosing where to bicycle. While bicycling on the sidewalk is discouraged or even prohibited in some places it is often preferred, especially among inexperienced bicyclists, or where other separated bicycling paths are not available. Perhaps not surprisingly, one study found that those who were injured while riding on a roadway had a higher relative risk of hospitalization (RR 2.36, 95% CI 1.92-2.90) and death (RR 11.42, 95% CI 3.76-34.66) compared with those riding in non-roadway locations.(**40**) Conversely, two Canadian studies by Aultman-Hall et al. found that the relative rate of injury was highest for bicyclists travelling on sidewalks, followed by off-road paths, suggesting that it is safest for bicyclists to travel on the road.(**65, 66**)

The discrepancy in the results of these studies may be a reflection of differences in the study designs and injury definitions. The first study relied on paediatric ED records for those less than 18 years of age. Injuries were defined according to reason for presentation (i.e., bicycle related event); consequently, only injuries necessitating medical attention in the ED were included. In the Aultman-Hall et al. studies, bicyclists were randomly selected to complete questionnaires about their bicycling habits and past injuries/falls. Thus, the number of previous injury events was self-reported. While a distinction was made between major or severe injuries (as defined by requiring medical attention) and less-severe injuries, all injuries were included in the analysis of bicycle location injury rates. The different study populations and injury definitions may suggest that for children, bicycling on a roadway is more dangerous. Children may not be aware of the increased risk that exists when sharing the road with vehicles, and lack experience in the traffic environment. Adults on the other hand may be more experienced and likely bicycle faster. Bicycle commuters in particular may blend in with motor-vehicles on the roadway. When travelling on non-roadway facilities, higher bicycling speed may create a risk for the bicyclist and other users, such as pedestrians. This however, is only speculation based on interpretation of the study findings. The scarcity of evidence on age differences in risk at various bicycling locations requires further examination.

Aultman-Hall et al. conducted their studies in two Canadian cities. In the second study location, the authors found that while the increased risk with riding on sidewalks remained, the relative rates of injury differed between cities, suggesting that other factors such as "urban form, traffic levels and the attitudes of drivers and bicyclists can affect bicycle safety".(**65, 66**) Recently, another Canadian study based in Montreal found that bicycling on a separated path, even along busy roadways, showed a lower relative risk of injury compared with bicycling on the street (RR 0.72, 95% CI 0.60-0.85).(**67**) The variation in the evidence on bicycling locations and injury risk reinforces the need to consider other elements, such as traffic and bicyclist volume, as well as the type of land use when examining how the environment relates to injury risk.

2.7.2 Traffic Flow Modifications

Some studies have examined crash rates at specific areas following interventions designed to facilitate traffic flow. A before-and-after study examining injury rates at locations where roundabouts were installed to replace signalized and non-signalized intersections revealed a significant *increase* (27%) in the number of injury incidents involving bicyclists and an even greater *increase* of severe injury events (41-46%).(**68**) Upon further analysis the authors found that different types of roundabout designs affected injury risk. Four different types of designs within the previous study sample were examined: mixed traffic, bicycle lanes within the roundabout, separate bicycle paths, and grade-separated bicycle paths. The number of crashes for each design was compared to events preceding the installation of roundabouts. The analysis revealed a 93% (95% CI 38-169%) *increase* in injury events for roundabouts with bicycle lanes, and an indication of a reduced number of injury events for the other three design types, although this result was not statistically significant.(**69**) A Swedish study had similar findings when bicyclist and motor-vehicle interactions were examined at two different roundabout designs. A greater number of serious conflicts (defined by time-to accident and conflicting speed) were observed at a roundabout with an integrated bicycle lane (4.6 conflicts/1000 bicyclists) compared with a roundabout with a separated bicycling path (2.3 conflicts/1000 bicyclists).(**70**) The results of these studies suggest that the type of modification implemented may influence bicycling injury rates, and that this should be considered when planning traffic design modifications.

Other examples of modifications to help facilitate traffic and bicyclist flow include the development of “bicycle streets” where bicyclists have the right of way over vehicles.(**1**)Additional measures implemented in Europe to encourage safe bicycling include special bike turn lanes and separate bike traffic signals.(**16**) While these modifications would appear to facilitate the use of a bicycle, there have not been any studies evaluating their effectiveness in increasing level of bicycle use or examining injury risk associated with these facilities.

2.7.3 Roadway Design

In a recent Calgary study, Rifaat, Tay and de Barros examined the effect of street patterns and other roadway factors on pedestrian and bicyclist injury severity in the event of a collision with a motor-vehicle. The authors found that "loop and lollipop" street patterns were positively associated with injury (RR 1.64, 95% CI 1.3-1.98).(**71**) This road pattern is very common in new urban areas and is characterized by a combination of cul-de-sacs and loop streets in a curvilinear design. In addition, divided roads with barriers were found to be positively associated with the risk of fatality (RR 8.93, 95% CI 8.04-9.82).(**71**)

In the Netherlands, a study was conducted to examine the link between intersection design, including bicycling infrastructure, and the risk of bicycle-motor-vehicle encounters.(**72**) Events were classified into "motorist at fault" (type I) or "bicyclist at fault" (type II) crashes, depending on which party had priority. The study showed that several factors were related to type I events, including 2-way bicycle paths (RR 1.75, 95% CI 1.01-3.03), red/high quality markings for bicycle crossings (RR 2.53, 95% CI 1.39-4.60), bicycle tracks located between 2-5m from the roadway (RR 0.55, 95% CI 0.30-0.99), and the presence of speed reducing measures for vehicles (RR 0.49, 95% CI 0.32-0.77). There was also a reduced risk associated with 4-armed compared with 3-armed intersections (RR 0.56, 95% CI 0.46-0.85).(**72**) Another study that examined the increase in risk created by various built environment factors on several types of collisions (e.g., two-vehicle, single-vehicle, pedestrian-vehicle, and bicycle-vehicle) had similar results; 4-leg intersections were shown to result in a 1.3% increase in vehicle-bicyclist collisions. The presence of strip malls also increased collisions (1.7%), and each additional mile of arterial thoroughfare corresponded to a 6.6% increase in vehicle-bicyclist crashes.(**73**)

A recent review separated characteristics related to intersections and straightaways.(**24**) For intersections, the authors noted that most of the evidence related to an increase in the risk of bicycling injury was with roundabouts without separated bicycle tracks. For straightaways, bicycling on sidewalks, multi-use trails, and major compared with minor roads increased risk while the presence of bicycle facilities decreased risk. Street lighting, paved surfaces, and low angled grades were also associated with reduced injury risk. Based on their review however, Reynold's et al. concluded that:

> "Although the effect of infrastructure design on bicyclist safety was first studied more than three decades ago, the literature on the topic remains remarkably sparse. This review highlights opportunities for more detailed and controlled studies of infrastructure and bicycling injuries."(**24**)

The authors suggest that many potentially relevant environmental configurations need to be studied more closely including street level features such as the number of roads intersecting, the presence of stop signs, driveways and parked cars, surface characteristics, traffic calming measures, and road/path curvature.(**24**)

2.7.4 Weather and Light Conditions

A small number of studies examining a broad range of individual and situational level bicycling injury risk factors have included measures of risks associated with aspects of the natural environment. Three studies noted an increased risk of fatality when bicyclists were riding after sunset in areas without streetlights, or at night (**46, 56, 71**) Bicycling in poor weather conditions such as fog, rain, and snow, has also been shown to increase injury severity.(**46**) This effect may be confounded by other factors, such as bicyclist or motorist behaviour and road surface conditions. It is possible that a relationship exists between weather and injury risk independent of other factors, but this has yet to be examined.

Table 2.3 presents a summary of studies that have examined environmental risk factors for bicycling injuries including outcomes and measures of effect.

Table 2.3 Environmental Risk Factors for Bicycle Injuries

Author	Study Design	Sample	Outcomes	Risk Factors	Effect Measures
Aultman-Hall, L.; Hall, F.L. (1998), Ottawa, Canada(**66**)	Cyclist survey with GIS† route mapping	n=1604 bicyclists recruited by distributing the survey on bicycles at workplaces and post-secondary institutions during summer 1995.	Travel exposure, injury events by location type	Bicycling location	RELATIVE RISK OF INJURY 1.0 on roads (reference category) 1.6 (95% CI 1.2-2.2) on off-road paths/trails 4 (95% CI 2.6-6.4) on sidewalks 1.0 off-road path/trail (reference category) 2.5 (95% CI 1.5-4.1) on sidewalk
Aultman-Hall, L.; Kaltenecker, M.G. (1999), Toronto, Canada(**65**)	Cyclist survey with GIS† route mapping	n=1360 bicyclists recruited by distributing the survey on bicycles at workplaces and post-secondary institutions during summer 1995	Travel exposure, injury events by location type	Bicycling location	RELATIVE RISK OF INJURY 1.0 on road (reference category) 1.8 (95% CI 1.7-1.9) on off-road path/trail 6.4 (95% CI 6.0-7.0) on sidewalk 1.0 off-road path/trail (reference category) 3.5 (95% CI 3.2-3.8) on sidewalk
Meuleners, L.B.; Lee, A.H.; Haworth, C. (2007), Perth, Australia(**13**)	Prospective case-series	n=151 bicyclists who presented to one of four emergency departments from September 2004-February 2005	Hospitalization	Bicycling location	HOSPITALIZATION ODDS RATIO 1.0 for metropolitan areas (reference category) 4.77 (95% CI 1.07-21.10) for rural areas 1.0 for bicycling on a highway (reference category) 0.09 (95% CI 0.01-0.73) for bicycling off-road such as sidewalks, driveways, yards, bicycle paths, or parking areas *Confidence intervals are based on my calculations from the author's data.
Mehan, T.J.; Gardner, R.; Smith, G.A.; McKenzie, L.B. (2009), USA (**40**)	Retrospective case-series	n=166 403 bicyclists under 18 years of age treated in emergency departments from 1990-2005	Hospitalization, fatality	Bicycling location	RELATIVE RISK OF HOSPITALIZATION 1.0 on non-roadway locations (reference category) 2.36 (95% CI 1.92-2.90) on roads RELATIVE RISK OF FATALITY 1.0 on non-roadway locations (reference category) 11.42 (95% CI 3.76-34.66) on roads
Lusk, A.C.; Furth, P.G.; Morency, P.; Miranda-Moreno, L.F.; Willett, W.C.; Dennerlein, J.T. (2011), Montreal, Canada (**67**)	Retrospective cohort with comparison locations	n=6 bicycle paths and corresponding reference streets Injury data were collected from emergency medical response records	Injury/crash rates per year and distance travelled	Bicycling location	RELATIVE RISK OF INJURY 1.0 on roadway (reference category) 0.72 (95% CI 0.60-0.85) for separated bicycle paths

Author	Study Design	Sample	Outcomes	Risk Factors	Effect Measures
Daniels, S.; Nuyts, E.; Wets, G. (2008), Flanders-Belgium(**68**)	Before-after, with comparison groups	91 roundabouts in a defined area, constructed between 1994-2000	Injury events or fatalities identified by traffic collision reports	Roundabouts	INJURY ODDS RATIO 1.0 on intersections (reference category) 1.48 (95% CI 1.09-2.01) for roundabouts SEVERE INJURY/FATALITY ODDS RATIO 1.0 on intersections (reference category) 1.44 (95% CI 1.00-2.07) for roundabouts
Daniels, S.; Brijs, T.; Nuyts, E.; Wets, G. (2009), Flanders-Belgium(**69**)	Regression analyses on effectiveness-indices from a previous study	90 roundabouts in a defined area, constructed between 1994-2000	Injury events or fatalities identified by traffic collision reports	Roundabout design	INJURY ODDS RATIO 1.93 (95% CI 1.38-2.69) for roundabouts with bicycle lanes compared with pre-installation
Bil, M.; Bilova, M.; Muller, I. (2010), Czech Republic(**56**)	Retrospective case-series	n=5428 traffic collisions involving adult bicyclists from 1995-2002	Fatality	Location geometry Light conditions	FATALITY ODDS RATIO 1.0 on straight roads (reference category) 0.65 (95% CI 0.51-0.84) on curved roads 1.0 during daylight (reference category) 1.4 (95% CI 1.08-1.8) after sunset 2.16 (95% CI 1.75-2.67) after sunset at locations without streetlights
Kim, J-K.; Kim, S.; Ulfarsson, G.F.; Porello, L.A. (2007), North Carolina, USA(**46**)	Retrospective case-series	n=2934 traffic collision reports involving bicyclists (all ages) from 1997-2002	Four injury severity levels: 1) fatal 2) incapacitating 3) non-incapacitating 4) possible or no injury	Location geometry Light conditions Weather Time of day	FATALITY ODDS RATIO 1.0 on straight roads (reference category) 1.89 (95% CI 1.38-2.61) on curved roads 1.0 during daylight (reference category) 2.34 (95% CI 1.42-3.88) after sunset at locations without streetlights 1.0 during clear conditions (reference category) 2.38 (95% CI 1.07-5.30) during inclement weather (fog, rain, snow, etc.) 1.0 after 10:00 am (reference category) 2.34 (95% CI 1.42-3.88) between 6:00-09:69 am *Based on my calculations from the authors data. Standard error of the coefficient was used to calculate the 95% CI, therefore limits should be interpreted with caution.

Author	Study Design	Sample	Outcomes	Risk Factors	Effect Measures
Rifaat S.M.; Tay, R.; de Barros, A. (2011), Calgary, AB. (**71**)	Retrospective case-series	n=2249 traffic collision reports involving bicyclists or pedestrians from 2003-2005	Injury or fatality	Time of day Street pattern Road design	FATALITY RISK RATIO 1.0 for no injury (reference category) 3.58 (95% CI 2.54-4.62) for night-time (12:01 AM-6:30 AM) INJURY RISK RATIO 1.0 for no injury (reference category) 1.64 (95% CI 1.3-1.98) for "loops and lollipops" 8.93 (95% CI 8.09-9.82) for divided roads with barriers
Schepers J.P.; Kroeze P.A.; Sweers W.; Wust J.C. (2011), Netherlands.(**72**)	Retrospective case-series with exposure estimation	n=540 intersections selected based on bicyclist and motor-vehicle volume (data from 2005-2008)	Number of motorist at fault (type I) events or bicyclist at fault events (type II)	Intersection design	RELATIVE RISK OF TYPE I CRASH 1.0 for one-way bicycle paths (reference category) 1.75 (95% CI 1.01-3.03) for two-way bicycle paths 1.0 for on-road bicycle lane or no bicycle lane (reference category) 0.55 (95% CI 0.30-0.99) for bicycle tracks 2-5m from roadway 1.0 for no markings at bicycle crossings (reference category) 2.53 (95% CI 1.39-4.60) for red colour, high quality markings 1.0 for no vehicle speed reducing measures at intersection (reference category) 0.49 (95% CI 0.32-0.77) for raised bicycle crossing or other vehicle speed reducing measure 1.0 for 3-armed intersections (reference category) 0.56 (95% CI 0.46-0.85) for 4-armed intersections

†Geographical Information System

2.8 "Safety in Numbers"

Another aspect of safe bicycling that has been examined is the relationship between the number of people bicycling and the frequency of motor-vehicle related bicycling injuries. Jacobsen used population data from California, Denmark, the Netherlands, the United Kingdom, and eight other European countries and found an inverse relationship between the number of people walking or bicycling and the likelihood that an individual would be struck by a motor-vehicle.(**17**) One explanation for this finding is that a greater presence of pedestrians and bicyclists influences the behaviour of drivers. This information supports initiatives to increase the number of people who walk or bicycle, suggesting that greater presence may lead to a reduction in pedestrian and bicyclist injuries, and that this will further increased visibility and awareness.

While this evidence is encouraging, the "safety in numbers" effect should be interpreted with caution. The use of aggregate level data in the investigation by Jacobsen limits the possibility of establishing a causal relationship between the number of bicyclists and the frequency of collisions, as the information used is not necessarily reflective of conditions at the micro (street, intersections, local community) level where injuries occur.(**74**) Further, due to the use of a cross-sectional design, the temporal direction of the effect cannot be disentangled. It is possible that the observed effect is in the opposite direction; that the locations with greater numbers of bicyclists were in fact safer to begin with and thus, were more likely to attract bicyclists.(**74**) Due to these challenges the evidence of a non-linear relationship between the number of bicyclists (or pedestrians) and collisions is an appropriate stepping stone for hypothesis generation. More conclusive studies that consider the effect of potential confounding factors including environmental conditions (e.g., traffic design, traffic laws/enforcement) and motorist and bicyclist behaviour norms are necessary before this relationship can be used as a basis for policy or transportation planning and injury prevention strategies.

2.9 Pedestrian Literature and Other Factors

Given the paucity of information on bicycling injury risk factors, particularly environmental determinants, it is useful to examine environmental determinants for pedestrian related injuries. A number of risk factors have been identified in the pedestrian injury literature.(**75**) In a review of this literature, Wazana et al. found that the risk of child pedestrian injury was elevated on roads with the following characteristics: greater traffic volume, higher speed limits, predominance of rental units, lack of play areas, unfenced play areas, a greater proportion of curb side parking, and shared driveways.(**75**)

More recently, Parkin and Howard noted a number of systematic reviews related to traffic calming measures.(**76**) Three systematic reviews identified reductions in pedestrian injury and fatality rates with the implementation of traffic calming measures, speed control methods, one-way systems, and street closures.(**77-79**)

Though not all of these factors may relate to bicycling injury, it seems reasonable that at least some will increase injury risk (e.g., curb side parking, higher speed limits and traffic volume). However, it is possible that many potential environmental determinants of bicycling injuries or bicycling safety are not found in the pedestrian injury literature.

2.10 Designing Bicycling Friendly Environments

A multitude of factors need to be considered when designing the environment to encourage safe bicycling. Land use, transportation, urban development, housing, environmental, and parking policies may all influence the level of bicycling and the safety of those who choose to bike. Designing facilities without regard to safety, perception of risk, or the needs of bicyclists is unlikely to encourage use. Further, the necessity of a coordinated, multi-faceted approach to designing and implementing measures to encourage bicycling cannot be overemphasized.(**16**)

Numerous studies have examined the relationship between neighborhood design and levels of physical activity and a few have focused on bicycling prevalence and bicycle mode share.(**80-83**) Presence of a designated bicycle lane on roadways (OR 5.4, 95% CI 1.29-22.60), length (km) of bicycle routes (OR 1.02, 95% CI 1.01-1.03), prevalence of traffic control devices (OR 2.90, 95% CI 1.19-7.02), and alternative routes (OR 4.49, 95% CI 1.55-13.00), have been shown to be significantly associated with recreational bicycling.(**80**) There is an indication that features related to safety, wide verge width (OR 0.89, 95% CI 0.78-1.01) and the absence of driveways (OR 1.43, 95% CI 1.18-1.73), may also be associated with recreational bicycling.(**80**) Other factors related to network layout that have been linked with bicycling include urban density and the connectivity of roadways and bicycle facilities.(**37, 81, 83, 84**) Higher density in urban areas results in shorter distances between locations, which encourages bicycling or walking in lieu of driving. Likewise, connectivity allows bicyclists to use more direct routes, resulting in shorter trip time and ease of travel. It is apparent that the built environment can be designed to promote bicycling for transportation and recreation, and that many modifiable aspects of the environment can be targeted in this regard.

The types of bicycle facilities available are an important aspect to consider as route preferences can dictate the choice to bicycle. Route or facility type preference can differ between socioeconomic or demographic groups, and experienced and non-experienced bicyclists. One survey found that respondents, both current and would-be bicyclists, were prepared to extend the length of their bicycle trip by up to twenty minutes in order to travel on a connected off-road bicycle path, as opposed to traveling on an unmarked roadway with curbside parking.(**38**) A survey of bicyclists in Seattle revealed that 49% of bicycle trips (utilitarian and recreational) occurred on various bicycle infrastructures, despite the fact that this infrastructure made up only 8% of the transportation network. This may indicate that some bicyclists are willing to travel out of their way to access bicycle facilities.(**82**) Areas that have succeeded in dramatically increasing the proportion of trips made by bicycle, such as the Netherlands and Germany, may serve as models for North American cities. In European countries, one of the main driving forces of increased bicycling levels appears to be the presence of separate bicycle facilities along heavily travelled roads and at busy intersections.(**16**) In particular, facilities should connect bicyclists to central destinations as opposed to directing them away from traffic dense areas, as is the case with many recreation oriented bicycle facilities.

A related aspect of the environment that has been examined is the relationship between perceived safety and real bicyclist injury risk. In a review of the effects of motorized traffic on levels of walking and bicycling, Jacobsen, Racioppi, and Rutter consistently documented that traffic perceptions, either the real or perceived danger, and the lack of appeal of walking or bicycling in traffic were associated with a decrease in these activities.(**85**) The responses from bicyclists in Seattle demonstrated that avoiding streets with heavy traffic was the second most important factor in route choice, following the desire to minimize trip distance.(**82**) Most studies agree that the presence of other road users (i.e., motor-vehicles) makes bicycling less safe, assuming that lower vehicle speeds and less traffic volume have positive effects on bicycle mode share (**81**); however, this generalization may not stand true for all levels of bicycling experience, as there is some evidence indicating that experienced bicyclists feel confident even in heavy traffic and choose to bicycle on busy streets as this tends to result in shorter trip distance/time.

In a review of controlled interventions to promote bicycling, Yang et al. noted that interventions that focused on promoting bicycling specifically (as opposed to active transportation or physical activity in general), including interventions that encompassed some type of bicycling infrastructure change, showed positive effects.(**86**) Population level interventions showed net increases up to 3.4 percentage points in the prevalence of bicycling or the proportion of bicycle trips.(**86**) This indicates that there are opportunities for modifying the built environment to promote bicycling, yet there remains a need to link this with injury risk.

This review of the literature on bicycling friendly environments demonstrates that numerous factors can influence the choice to bicycle, and that these factors are inter-linked. For example, urban density is related to connectivity insofar as it is more feasible to develop connected bicycle networks in dense areas. While many studies have examined the relationships between neighborhood design, traffic, and levels of bicycling, very few studies have linked these features of the environment with injury risk, or have examined these features in relation to objective measures of safety.

Table 2.4 includes various features of the environment that have been suggested to increase bicycling levels, and which may have a relationship to injury. An upward arrow indicates that there is evidence that bicycling levels or safety may be increased with the presence of these features. A downward arrow indicates that the features may discourage bicycling, or decrease bicyclist safety. Of particular interest are the (shaded) features that appear to encourage bicycling but have the opposite effect on safety. By incorporating more scientific evidence on how environmental features may relate to injury and bicycling levels, this type of table would be useful in designing bicycle friendly environments, by adopting those features that have the dual effect of increasing bicycling and reducing injury risk.

Table 2.4 Suggested Effects of Environmental Characteristics on Bicycling levels and Safety

Feature	Bicycling level	Risk
Designated bicycle lane	↑	↓
Increased length of bicycle route	↑	↑
Traffic control devices (shared or bicycle specific)	↑	↑ & ↓
Alternative routes	↑	↑ & ↓
Connected, off-road pathways	↑	↑
Traffic volume (more)	↓	↑
Traffic speed (greater)	↓	↑
Street connectivity	↑	↑
Urban density	↑	↓

2.11 Measuring the Environment

Research indicates that certain aspects of the environment influence physical activity levels. As such, tools have been developed to assess or measure different characteristics of an area that may have an impact on levels of activity, or the willingness to choose active modes of transportation. An *audit instrument* is “a tool used to inventory and assess physical environmental conditions associated with walking and bicycling”.(**87**) Audit instruments are used to conduct *environmental audits*, systematic observation assessments of factors in the physical and social environment (e.g., recreation facilities, sidewalks, roadway characteristics) that inhibit or accommodate physical activity.(**88**) Audit instruments have been developed for a variety of users and applications, some for scientific research, and others for use by laypersons to evaluate neighborhoods for characteristics that promote or discourage physical activity.(**89**) Audit tools are used to measure and evaluate various items (variables) related to walking and bicycling, and have emerged from a range of disciplines including transportation planning, urban design, engineering, and public health.

The choice of an acceptable tool for any evaluation necessitates careful consideration of the variables of interest and the intentions for the research. Other factors to consider in the choice of an audit instrument include the amount of training required to familiarize the user, the length of time it takes to administer the audit, the method of data collection (e.g., pen and paper or electronic), as well as the tool's demonstrated psychometric properties. Unfortunately, the use of such tools is relatively recent and thus many tools have yet to undergo rigorous reliability testing. The following section briefly reviews some of the instruments available that were considered for this study, and presents the rationale for choosing one particular tool.

As interest in environmental determinants of physical activity is increasing, the list of available audit instruments is expanding. In a 2003 review, Moudon and Lee identified 31 instruments designed to audit the physical environment for both recreation and transportation related walking and bicycling.(**87**) The review emphasized the importance of incorporating several dimensions of factors in any instrument, including intra- and interpersonal factors, environmental factors, and trip characteristics.(**87**) The authors stipulate that "most environmental audit instruments address environmental factors and trip characteristics, but only a few include personal determinants for specific populations, such as age and bicycling skill level."(**87**) The instruments reviewed were categorized into four purposes: 1) inventories, which list the features of the environment present that might influence the amount of walking or bicycling; 2) route quality assessment tools, which measure and rate roadway designs; 3) area quality assessment tools, which are used for policy and planning purposes; and 4) estimates of latent demand, which are used to estimate the demand for non-motorized transport in an area.(**87**) For this project, instruments in the first three categories warranted a closer examination.

Hoehner et al. designed an audit tool that was an adaptation of several existing instruments.(**89**) While it was not included in Moudon and Lee's review because it was developed in 2005, it could be categorized as a hybrid of inventory and area quality assessment tools. The aim of the Active Neighborhood Checklist (the "Checklist") was to create a tool that could be used by a variety of users, including laypersons. The Checklist assessed land use characteristics, sidewalks, shoulders and bike lanes, street characteristics, and quality of the environment for pedestrians.(**89**) The mean observed (percent) agreement for all items of the Checklist was 0.87 (range 0.61-1.00).(**89**) The agreement was measured by kappa [κ], a measure of chance corrected proportional agreement, (**90**) and was substantial (κ=0.68; range 0.21-1.00) for all items.(**89**) Landis and Koch suggest that κ statistics between 0.0-0.19 are indicative of poor agreement, 0.20-0.39 represent fair agreement, 0.40-0.59 moderate agreement, 0.60-0.79 substantial agreement, and values above 0.80 indicate almost perfect agreement.(**90**) Both observed agreement and kappa measures demonstrated substantial to perfect reliability for almost all items in the Checklist. While the Checklist had high reliability, a short training time, short administration time, and fewer variables than comparable tools, for our study purposes, the benefit of these features was offset by the fact that the Checklist did not include some potentially important features related to bicycling. It did not include measures of street connectivity, which has been shown to significantly influence bicycling for transportation (**37**), or characteristics of intersections, presence of street lighting, and traffic volume, all previously been shown to relate to bicycling injury rates.(**24, 85, 91**)

The Irvine-Minnesota Inventory (IMI) was developed by researchers in the United States to measure features of the built environment that support active living.(**92**) The authors designed the tool after reviewing the literature to identify built environment features that influence physical activity, particularly walking. Their review was guided by a framework which included the following aspects: accessibility, defined as "the perceived ease with which destinations can be reached", pleasurability (i.e., attractiveness), perceived safety from traffic, and perceived safety from crime.(**92**) The authors concentrated on features of each of these aspects that could be measured objectively; however, some subjective measures were eventually included in the tool. The development phase of the IMI included focus groups, field surveys, consultations with a panel of experts, and pilot testing of the draft inventory of features, including reliability testing.

The final inventory included over 160 items and was made available in both paper and electronic survey form. The IMI was designed to be used by two auditors and the final inventory was adopted after some reliability testing. Inter-rater reliability was assessed at two study sites. The results from one site demonstrated that 76.8% of the variables had

>80% agreement, while at the second study site 99.2% of the variables showed this level of agreement.(**93**)

Despite high observed agreement, it was noted by the authors that the length of the tool and the training required to use it created a feasibility issue, and they proposed that researchers could use a subset of the items included depending on their research focus.(**92**) Even so, the tool was developed with walking in mind and did not include some features of walking/bicycling paths that may be relevant to us, such as path width, distance from the curb, and connectivity. Bicycling research may benefit from excluding some of the features included in the inventory and including others that have been shown to be related to bicycling. To examine the relationship between the built environment and bicycling injury, many modifications of the IMI would be necessary. Further, the length of the inventory (i.e., the time necessary to complete it) was a deterrent to its selection, especially given that it was unclear whether collecting this level of detail was necessary to understand the relationship between the built environment and bicycling injury risk.

Another inventory instrument considered was the Systematic Pedestrian and Cycling Environment Scan (SPACES) developed by Pikora et al.(**88**) Prior to the development of the SPACES, Pikora et al. worked on a conceptual framework similar to that proposed by Day et al. To identify and rank variables to include in the framework a Delphi[1] study was conducted with a panel of experts. The results of the study provided a hierarchical framework with four features of the environment deemed most important:

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[1] The Delphi method is a multi-phase approach used to collect judgements and derive consensus from a group of experts. This approach is used in various fields of research and is often applied in situations where there is a lack of knowledge about a particular problem 94. Skulmoski GJ, Hartman FT, Krahn J. The delphi method for graduate research. *Journal of Information Technology Education* 2007 2007;**6**: 1-21.

1) functional, 2) safety, 3) aesthetic, and 4) destination features. Each *feature* encompassed a list of *elements* which influenced it, and then *items* within those elements were defined as "factors that have the potential to be changed to improve an element."(**88**) For example, within the safety feature section, one element considered was the presence of roadway crossings. The type of crossing would then be an item that could potentially be modified. Figure 2.1 from the original article on the development of the SPACES illustrates the framework hierarchy. After multiple revisions of the initial framework, the Delphi study results produced a refined list of variables that were deemed important to include in a data collection tool; subsequently, the SPACES tool was developed.

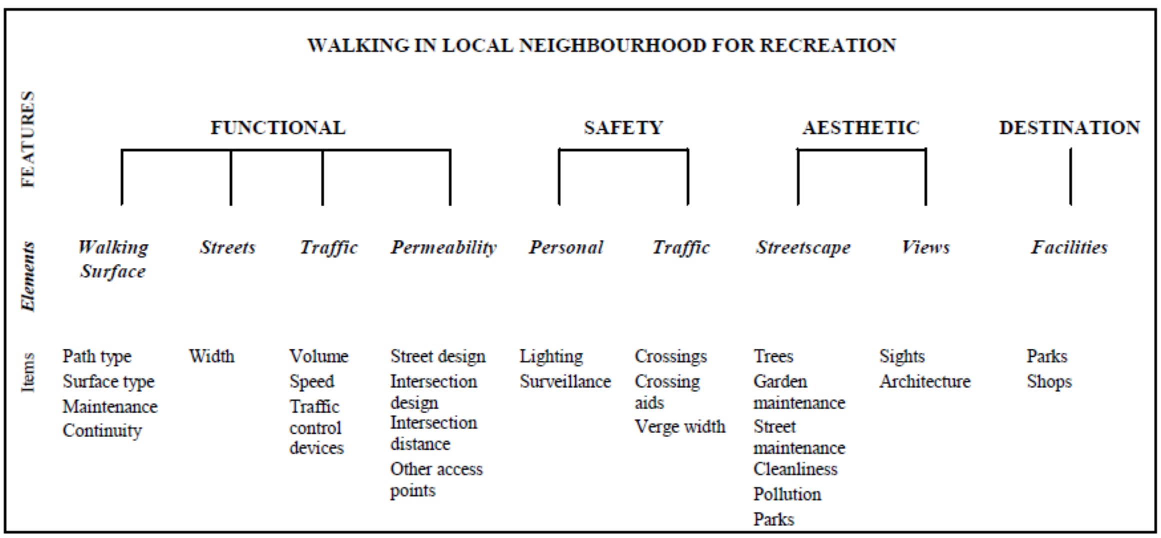


Figure 2.1 SPACES Conceptual Framework Hierarchy(88)

The SPACES was designed as a checklist style instrument with 37 items related to the assessment of an area for walking and bicycling. The tool was tested on selected segments within a 400-metre radius of a person's residence. This was estimated to be the distance a person could reasonably travel on foot in 5 minutes.(**95**) The instrument captured data on street-level attributes and therefore provided a “fine grained” assessment of the built environment surrounding a specific site, such as a person’s home or an injury event location. The tool was separated into four sections, each addressing a different aspect of the environment. It included measures of the type of land use, characteristics of the walking or bicycling path, roadway characteristics, aesthetics, and accessibility. Data on two sides of a segment could be recorded if necessary. The inter- and intra-rater reliability of the SPACES tool was evaluated and found to be generally high, even when more subjective elements of the tool were analyzed.(**95**) The tool required limited training and administration time, observers reported that the tool was easy to use, and a comprehensive user manual was available.

In addition, the SPACES measured several variables that have been demonstrated to relate to bicycling, such as connectivity, which other instruments did not incorporate. For these reasons, the SPACES was chosen as the most appropriate tool for the present study. For the most part, the SPACES was comprehensive enough to record the information considered to be important in assessing the environment for injury risk factors. However, to record some additional objective measures we deemed important (e.g., presence of curb cuts, type of parking), a supplementary audit form was developed. This supplement also allowed auditors to record field notes or observations that might not be captured in the SPACES. Details about our environmental audit data collection procedures are found in Chapter 3.

One other audit instrument warranted close examination. A group of researchers in the United States developed an instrument based on the SPACES tool in an attempt to adapt SPACES to the North American context. The Pedestrian Environment Data Scan

(PEDS) (**96**) retained the majority of the variables included in the SPACES, with some modifications and additions. PEDS assessed in greater detail features of pedestrian infrastructure, road characteristics, and building access. In addition, PEDS was available in paper format, as well as for handheld technology. Extensive training and protocol manuals existed to accompany the tool, and inter- and intra-rater reliability testing had been conducted. The results of the reliability testing were mixed, revealing that while most objective measures were highly reliable ($\kappa > 0.75$), some subjective measures such as the articulation of building designs and the level of enclosure demonstrated low agreement scores ($\kappa < 0.40$).(**96**) The majority of elements demonstrated substantial levels of agreement, and to improve the reliability of lower-scoring items, some modifications were made. For example, the number of response choices on some of these items was limited. The authors emphasized that the tool was versatile insofar as the settings where it could be applied (urban, suburban, rural), and highlighted that PEDS was efficient and easy to use.

The PEDS instrument encompassed most of the aspects relevant to our examination of environmental risk factors; however, the tool was focused on assessing the environment for walking. Another drawback was the format of the tool, which required that two forms be completed for locations where both sides of a segment were being evaluated (resulting in four forms when two auditors were collecting data). We anticipated that this would be the case for the majority of our audit locations and thus, it would be more time consuming to administer the PEDS audit and to enter the data. For these reasons we opted to use the original SPACES tool. The relevant variables that had been added to SPACES in the development of PEDS were included in our supplementary audit tool, which allowed us to collect all the information considered important in both of these instruments.

2.12 Summary of Literature Review

This review of the literature surrounding bicycle injuries and the environment demonstrates several key points. First, the importance and burden of unintentional injuries, bicycling injuries in particular, is evident. Bicycle related injuries are a major cause of morbidity. Unfortunately, severe injuries, often the result of collisions with motor-vehicles, can result in death. Further, children are disproportionately represented in almost all types of bicycle crashes, including the high number of crashes that occur on non-roadway locations such as sidewalks, driveways, and multi-use or designated pathways. Fortunately, opportunities exist for preventing many of these injuries. This task begins by identifying personal and environmental risk factors for bicycle injuries.

Identifying and addressing risk factors for bicycle injuries will not only help to prevent injuries, but by making bicycling safer, may encourage more people to use a bicycle for transportation and recreation. Low levels of physical activity can lead to weight gain and associated health problems. As the obesity epidemic becomes a major public health issue, initiatives to promote physical activity are increasingly important. Integrating activities such as bicycling into daily life is relatively easy, and an option for many. Further, the barriers that exist for getting people to ride a bicycle are for the most part modifiable. Providing bicycle facilities that allow bicyclists to be connected to key locations by offering designated bicycle lanes on roadways and separated facilities in heavy traffic areas are some of the proposed methods of making bicycling more appealing and accessible.

An important aspect of making our environment bicycle-friendly is to consider the factors that have been shown to encourage or inhibit physical activity. This includes consideration of land use mix, infrastructure, aesthetics, and safety, as well as personal factors. Interest in the determinants of physical activity has led to the development of instruments designed to measure the environment for walking and bicycling. These tools have been used in a variety of applications designed to increase the number of pedestrians and bicyclists, but have yet to be used to assess the safety of the environment by identifying specific risk factors for bicycling injuries.

The importance of preventing bicycle-related injuries and the need to increase levels of physical activity in our population make addressing safety issues in our environment a priority. In this study, we examine the relationship between aspects of the environment and bicycling injury risk. The findings will inform stakeholder groups about opportunities to make our environment more bicycle-friendly.

Chapter Three: Methods

3.1 Research Design

This study used a matched case-control design. Both cases and controls were injured bicyclists who presented to one of the participating EDs. Two case groups of injured bicyclists were identified and compared with corresponding control groups. Case groups were defined by the mechanism of injury (motor-vehicle collision) or injury severity (see definitions section 3.4). Each case was matched on time and day with up to three controls. We combined data on bicyclists' personal characteristics, crash circumstances, and injury outcomes with information on the environmental characteristics of the crash sites obtained by conducting environmental audits of the injury event locations.

This study was an extension of the ongoing Cycling Injury Risk Factor (CIRF) study, which began in May 2008. A brief description of the CIRF study is provided below.

3.2 Cycling Injury Risk Factor Study (CIRF)

The CIRF study was a prospective study with data collection spanning over three years (May 2008-October 2010). The main objective of the study was to determine if high visibility (e.g., clothing color, bike reflectors, helmet color) reduced the risk of a bicyclist being struck by a motor-vehicle. The secondary objectives were: 1) to determine if high visibility reduced the severity of an injury when a bicyclist was struck by a motor-vehicle; and 2) to determine the quality of reported visibility and other risk factor information in injured bicyclists.

3.2.1 CIRF Study Design

The CIRF study used a prospective case-control design. Cases were bicyclists assessed in EDs for an injury due to being struck by a motor-vehicle, while controls were bicyclists assessed for an injury that occurred in non-motor-vehicle related incidents. Bicyclists were recruited from participating EDs in Calgary (Alberta Children's Hospital [ACH], Foothills Medical Centre [FMC], Peter Lougheed Centre [PLC] and Rockyview General Hopsital [RGH]) and Edmonton (University of Alberta Hospital [UAH], Stollery Children's Hospital [SCH] and North East Community Health Centre [NECHC]), Alberta.

3.2.2 CIRF Data Collection

CIRF research assistants (RAs) liaised with ED staff and scanned the Regional Emergency Department Information System (REDIS) to identify potential subjects. When an injured bicyclist was identified, the RA asked the medical staff when it would be appropriate to talk to the patient (and the family) about the study. When patients were approached, they were given a consent form (APPENDIX A: Participant Consent Form) to read and encouraged to ask questions before deciding whether to participate. The RA conducted a 15 to 20 minute interview with consenting bicyclists using a standard questionnaire (APPENDIX B: Cyclist Data Collection Form). Bicyclists were asked questions about the circumstances surrounding their crash, such as where they were bicycling, weather conditions at the time, their clothing, and the use of protective equipment and visbility aids. Once the bicyclist's personal and crash information was recorded, the RA obtained the injury diagnosis and disposition from REDIS or the patient's medical chart.

When RA coverage was not available in the ED, bicyclists may have been missed. In some cases, verbal consent in off hours was obtained by the ED staff and documented on the chart. Alternatively, these bicyclists were identified by retrospectively scanning the daily list in REDIS for bicycle related injuries. When an injured bicyclist was identified in REDIS, the RA accessed the clerical screen and recorded the patient's contact information (name, address, and telephone number) on a follow-up sheet. From the clinical screen, the RA obtained the injury diagnosis and disposition or, if this information was not available, the health record number (HRN). The HRN was used to order the patient's medical record for that specific ED visit if the patient was later enrolled in the study. The RA sent the missed patients an information package containing a study introduction letter and a consent form. Five to seven days after mailing the information, the RA telephoned the patient to request their participation in the study. If the patient provided verbal consent, the RA conducted a telephone interview using a standardized data collection form. The RA made a maximum of six attempts, on different days and at different times, to contact the patient.

Every 6 months, the CIRF research coordinator contacted the Office of the Chief Medical Examiner (ME) for information on bicyclists who died as a result of their injuries. Out of respect, the families of those individuals were not contacted, but information obtained about the circumstances surrounding their death was collected from the ME's report. For study participants who were struck by a motor-vehicle (cases), Alberta Traffic Collision Reports (APPENDIX C) from the Calgary Police Service (CPS) and Edmonton Police Service (EPS) were requested. As required by the Freedom of Information and Privacy Protection Act, the CIRF investigators established an "Agreement for Access for Personal Information for Research or Statistical Purposes" with the ME's office, the CPS and the EPS. Information from the bicyclist interview, and, if applicable, the Traffic Collision and ME reports was then combined for the purposes of analysis.

The CIRF study results will provide a comprehensive understanding of many risk factors for motor-vehicle related bicycle injuries. In particular, the study will go beyond current evidence on the protective effect of bicycle helmets to examine other potential protective measures, specifically visibility aid use.

3.3 Extending the Examination of Bicycle Injury Risk Factors

To build on the information on bicycling injury risk factors collected as part of the CIRF study, this study combined these data with information on the specific characteristics of injury event locations, for a targetted examination of environmental risk factors for bicycle injuries. The precise location of injury events was determined from bicyclist responses to Section 1: Crash Details in the Cyclist Data Collection Form (APPENDIX B). The locations studied were selected based on the injury circumstances and injury severity of bicyclists enrolled in the CIRF Study. These factors also determined the case-control status of participants.

3.4 Case Definitions

Cases were injured bicyclists who presented to the ED at one of the seven study sites in Calgary or Edmonton, Alberta. Two case definitions were adopted: motor-vehicle cases and severely injured cases.

3.4.1 Motor-Vehicle Cases

Motor-vehicle cases were bicyclists assessed at one of the study EDs because they were injured in a collision with a motor-vehicle (e.g., car, truck, sport utility vehicle, bus, etc.).

3.4.2 Severely Injured Cases

Severely injured cases were bicyclists assessed at one of the study sites for an injury and who were subsequently admitted to hospital (hospitalized).

3.4.3 Motor-Vehicle Severely Injured Cases

In the event that a bicyclist injured in a collision with a motor-vehicle was hospitalized, they were considered in both case groups.

3.5 Control Definitions

Two control groups were chosen in order to conduct an accurate comparison based on bicycling location and exposure to motor-vehicles. Both control groups – road/sidewalk controls and minor injury controls, were bicyclists who were assessed and discharged from one of the ED study sites.

3.5.1 Road/Sidewalk Controls

This control group consisted of bicyclists who were assessed at one of the ED study sites for an injury sustained while riding on the road or sidewalk. A road/sidewalk control could be selected for comparison with either case group (motor-vehicle cases and/or severely injured cases).

3.5.2 Minor Injury Controls

These controls were bicyclists who were assessed at one of the ED study sites for an injury sustained while riding a bicycle, regardless of bicycling location (e.g., bike paths). This control group was used as the comparison group for severely injured cases exclusively.

3.6 Exclusion Criteria

The following exclusion criteria were adopted for cases and controls:

1. Non-bicycling injuries (e.g., pedestrian injuries).

2. People who were not injured while riding a bicycle (e.g., tripped over a bicycle).

3. Injuries that occurred at the following locations:

    a. On private property.

    b. In a commercial mountain bike terrain park.

    c. In a skateboard or BMX park.

    c. On unpaved trails used for off-road trail riding or mountain biking.

    d. Event locations outside of our defined catchment area (i.e., Calgary or Edmonton city limits).

4. Bicyclists who did not provide sufficient details about the precise crash location.

5. Bicyclists with insufficient contact information or who did not speak English.

3.7 Matched Case-Control Design

The choice of a matched case-control design was based on the concern that in a study of this nature, cases and controls may differ in characteristics or exposures other than the ones under consideration. Of particular concern were the time and day of the injury event, particularly because factors we were interested in examining, such as traffic and bicyclist volume, would be expected to vary by time and day. As such, cases and controls were individually matched based on time and day of the week, within a two week time span. This was done to ensure that the distribution of the cases and controls by time of day and day of the week was similar.

Each case was individually matched with a minimum of one and a maximum of three controls (more information on the sample size determination is found below in section 3.8). Cases were matched with controls injured in the two weeks prior or two weeks after their injury event. Within this time frame, up to three controls injured nearest to the time of the case (± two hours) were selected. Weekdays were treated equally, as were weekend days. The weekend was defined as 16:00 Friday, to 05:00 Monday. For example, if a case was injured at 10:00 on Monday, controls injured on any weekday, between 08:00-12:00 were eligible.

For cases without three eligible controls, the maximum number of eligible controls was selected (at least one). Controls were selected with replacement. That is, if a bicyclist was an eligible control for multiple cases, they were selected for each appropriate set. In this scenario the control location was visited multiple times corresponding to each case event. Controls were matched to a maximum of three cases.

If a bicyclist was included in both case groups (motor-vehicle collision *and* severe injury) we attempted to select six corresponding controls: three road/sidewalk controls, and three minor injury controls. If there were not six eligible controls, the maximum number was selected.

Achieving a case-control ratio of 1:3 was feasible given that during the first two years of data collection for the CIRF study, approximately 6 (in Edmonton) to 8 (in Calgary) non-motor-vehicle related injured bicyclists were enrolled for every motor-vehicle related injured bicyclist. Also, 8 (Calgary) to 10 (Edmonton) bicyclists with minor injuries were enrolled for every bicyclist with severe injuries (Tables 3.1 and 3.2). There was a fairly even distribution of case bicyclists over the 18 weeks from May to August 2008 with no more than five cases enrolled each week.

Table 3.1 Calgary Enrollment May 1 to August 30, 2008 (excluding injuries in terrainparks, BMX racetracks and occurring outside of the Calgary area)

	Injury Severity			
Crash Type	ED treatment	Hospitalized	Missing	Total
Control	213	22	16	251
Case	21	3	7	31
Unknown	4	3	0	7
Total	238	28	23	289

Table 3.2 Edmonton Enrollment May 1 to August 30, 2008 (excluding injuries in terrain parks, BMX racetracks and occurring outside of the Edmonton area)

	Injury Severity			
Crash Type	ED treatment	Hospitalized	Missing	Total
Control	126	11	5	142
Case	21	2	0	23
Unknown	0	1	0	1
Total	147	14	5	166

The research coordinator in each city conducted the matching manually using a spreadsheet (Microsoft® Excel). Each eligible bicyclist enrolled in the CIRF study was entered into a ledger. When a case bicyclist was identified, the research coordinator examined the ledger to identify potential controls. Matched sets (4 bicyclists) were completed as bicyclists were enrolled in the the CIRF study. Once the three controls injured nearest the time and day (weekday or weekend day) of the case were identified, the set was recorded as being complete. Figure 3.1 illustrates the case-control selection process.

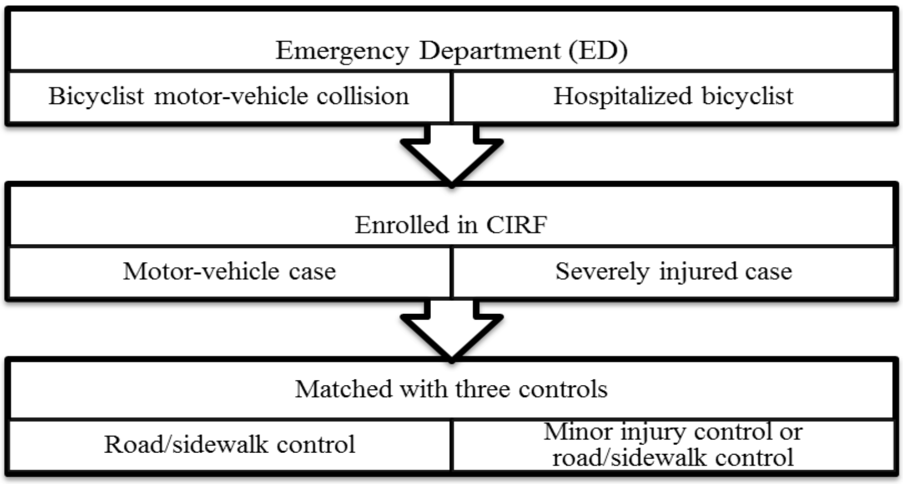


Figure 3.1 Case-control Selection Process

3.8 Sample Size

There were 31 bicyclists struck by a car and enrolled in the CIRF study in Calgary and 36 in Edmonton from May through August of 2009. Because little is known about the environmental risk factors we investigated in this study, our results will provide a basis for effect estimates that can be used in future studies. However, if we assumed only a *10%* prevalence of the risk factor among the controls, we would have over 80% power to detect an odds ratio of 3 with 3 controls per case. With *50%* prevalence of the risk factor among the controls, we would have over 80% power to detect an odds ratio of 2.5 with 3 controls per case. With *70%* prevalence of the risk factor among the controls, we would have over 80% power to detect an odds ratio of 3 with 3 controls per case. Considering that Aultman-Hall and Kaltenecker found a 7.9-fold greater risk of major injury on sidewalks compared with roadways, (**65**) we anticipated sufficient power to detect such effects.

Based on the information available and the afrementioned assumptions, our estimated sample size was 50 motor-vehicle cases and 50 severely injured cases (25 of each group in both Calgary and Edmonton). Anticipating a ratio of 1:3, we expected to visit 200 bicycling crash locations in each city, for a total of approximately 400 locations.

3.9 Procedures

Several tools were used to assess and measure individual and environmental risk factors for bicycle injuries. The independent environmental variables examined included, but were not restricted to: traffic volume, land use, path characteristics (e.g., location, material, slope, condition, and obstructions), road conditions, curb presence/height, parking, traffic control devices, lighting, surveillance, aesthetics, connectivity, and bicyclist volume. Individual independent variables of interest included: age, sex, and bicyclist speed.

3.9.1 Bicyclist and Crash Information

Data on individual risk factors and crash circumstances were collected as part of the CIRF bicyclist interview. The information collected during the interview included a narrative description of the crash, time, date, location, information about the bicyclist's experience and previous crashes, helmet and protective equipment use, and demographics. If pertinent information about the bicyclist, crash circumstances, or crash location was missing, bicyclists who had agreed to be contacted for follow-up were re-contacted by telephone and questioned a second time to collect the necessary information. Injury and diagnosis information was collected from participating bicyclists' medical records for the ED visit in question. The research coordinator or a delegated research assistant reviewed the medical charts. The injury and diagnosis information was recorded on the Cyclist Data Collection Form (APPENDIX B).

3.9.2 Environmental Audits

Information on the environmental characteristics of each location was collected by direct observation. Prior to data collection, 6 RAs were trained in each city by the research coordinator on how to conduct the audits. The auditors practiced using the data collection and measurement tools in the field prior to conducting their first audit.

The research coordinator or delegated research assistants visited the locations as close as possible to the time and day as the initial case injury event. When resources permitted, two auditors visited the location and independently recorded their observations. Blinding of case-control status was used in order to minimize the possibility of introducing recorder bias when observing locations. For example, the knowledge of the case-control status of a location might influence the level of detail of the information recorded. For most audits, one auditor was blinded to the case/control status of the location. On some occasions, both auditors were blinded. When it was not possible for two auditors to visit the location, the auditor may or may not have been blinded, depending on who was available to conduct the audit. The research coordinator was not blinded to the case-control status of locations at any time. Auditors travelled to the locations using public transportation or on bicycles, except when this was not possible due to distance or time constraints.

3.9.3 Data Collection Tools

Several tools were used to collect information on the environmental characteristics of crash locations. The following sections describe each of these tools and how they were applied in the field.

3.9.3.1 Systematic Pedestrian and Cyclist Environment Scan (SPACES)

Data on street level attributes were collected using the SPACES (APPENDIX D) developed by Pikora et al.(**95**) This is a reliable tool for measuring the environment as it relates to walking and bicycling, and it has been used in its original form or adapted in several other studies.(**80, 97-99**) SPACES and the accompanying user manual are publicly available.(**100**)

The SPACES is a one-page paper checklist divided into five sections assessing land-use, path characteristics, roadway characteristics, aesthetics, and connectivity. Where applicable, information can be recorded separately for each side of the location examined. Each of the 37 questions has several response choices. For some items, response choices are mutually exclusive, for example, whether the predominant features of each side are identical (yes or no). When necessary, multiple responses can be selected. For example, multiple path obstructions (poles, trees, chairs, etc.) can be selected. The auditors reported that the SPACES was easy to use and that the response choices were comprehensive. Once auditors were familiar with the tool, administration time ranged from 5-10 minutes.

The SPACES was originally designed to capture information on a pre-determined 400-metre area around a person's home.(**95**) This area was selected as it was proposed to be the distance a person could comfortably walk in approximately 5 minutes. It describes the micro level characteristics of the immediate area around one's home, some of which might have a direct impact on walking or bicycling. For this study, we were concerned with the micro level characteristics of crash locations. As such, the segments examined did not have a specific length, but rather, were determined based on the nature of the location. Auditors stood as close as possible to the crash site, and observed the immediate surrounding area. When two auditors were present they agreed on limits for the area to observe. In general, the area under observation was approximately equal to one street block. However, this varied depending on the type of location. For example, some pathway audit areas may have been shorter due to limited visibility when paths wound around corners. Auditors walked around each location to make sure they accurately recorded information that was difficult to examine standing at the crash site, for example, to measure the width of the path.

The SPACES was easy to use, quick to administer, and included many of the variables that have been shown to relate to bicycling. However, a few variables of interest were not included in the tool and as such an additional audit tool was developed to record this information.

3.9.3.2 Environmental Audit Supplement

The Environmental Audit Supplement (APPENDIX E) was developed by the research coordinator to obtain greater detail about characteristics of the path and roadway at the location. The Supplement contained four questions: path width, intersection design, curb cuts, and parking. One of the auditors measured the width of the path and the height of curb cuts (if applicable) using a standard measuring tape. Both auditors recorded the measurement information in centimetres. If the location was an intersection of a path with another facility (road, another path, or other) this was recorded. The presence of parking spaces and the type of parking (on street parallel, on street angle, parking lot, etc.) was also noted.

Further, all case events were designated as: mid-block ride-outs, driver inattention/error, bicyclist inattention/error, or other, as per Rowe et al.(**44**) This was done to characterize the event and to examine injury mechanisms and outcomes. The type of event was assessed by looking at the bicyclist's narrative description of the crash, as well as the bicyclist's response to the question "were you at fault in the crash". We did not have enough detail about each crash to further categorize bicyclist or driver error by the type of action performed by the at-fault party. However, since Rowe at al. found that types of crashes differed by age groups, we examined type of crash by age categories.

The Environmental Audit Supplement also included a section for auditors to record field notes or comments. This space was used to record pertinent information that was not included as part of the SPACES or Supplement data collection forms. If the information recorded in this section was related to a specific question on the SPACES or Supplement forms, auditors recorded the corresponding question number. This additional information was included in the analysis where appropriate.

3.9.3.3 Bicyclist and Traffic Volume

Data on the number of bicyclists seen and traffic volume were recorded for each location. Bicyclist counts were taken to examine bicyclist volume as an independent predictor of injury. Traffic volume was recorded as it has been found to be a determinant of levels of bicycling and walking in an area (**85**), and intuitively, may be related to injury risk, although this has yet to be established.

Using the Cyclist Flow Data Collection Form (APPENDIX F), auditors counted the number of bicyclists observed at each location during two 15 minute periods centered on the time of the case injury event. A bicyclist was counted if they entered the auditor's field of view. Bicyclists were counted only once, even if they were seen multiple times (e.g., if they were circling in the area). Additionally, the number of bicyclists wearing helmets was recorded. At the end of each 15 minute period the number of bicyclists as well as the number wearing a helmet was summed. The sums of each period were totalled.

While one auditor counted bicyclists the other auditor counted the number of motor-vehicles that entered their field of view during the two 15 minute periods, using mechanical traffic counters. Depending on the volume of traffic and the information available about the crash circumstances, one of three traffic counting methods was adopted. If information was available about the bicyclist's direction of travel at the time of the crash, traffic was counted in the direction of impact. That is, in the direction from which the bicyclist was hit. Similarly, if the location was a heavy traffic area, the auditor counted traffic in one direction of travel during each period. This was necessary when there were multiple lanes of traffic, and at peak traffic times. If the location was a low-volume area, traffic was counted in both directions during both periods. This information was recorded on the Traffic Flow Data Collection Form (APPENDIX G).

Given that multiple counting methods were used, the 15 minute vehicle counts were not directly comparable for all sites. In addition, traffic counts needed to be calculated to a standard unit of time (per ½ hour). To address these issues several steps were taken:

a) If both directions were counted, the average of both periods was calculated. The average was multiplied by 2 for total vehicles/half hour.
b) If one direction was counted per period, the number of vehicles in period 1 (p1) and period 2 (p2) were added to calculate 15 minute totals for all directions. This number was multiplied by 2 for total vehicles/half hour.
c) If the bicyclist's direction was counted, counts were examined individually to determine what counting method was used. If the period counts had >20 vehicle

difference, it was assumed that traffic was counted for each direction separately.

Calculations were done as per a) *or* b).

Traffic volume was then categorized based on Roberts et al.(**101, 102**) who have previously studied its relationship with pedestrian injury risk. Roberts et al. used 4 categories of traffic volume: 1) ≤250 vehicles/hour; 2) 250-499 vehicles/hour; 3) 500-749 vehicles/hour; 4) ≥750 vehicles/hour.(**102**) In this study, there were few sites in the two middle volume categories (18 sites for category 2, 17 sites for category 3); these categories were collapsed to yield 3 volume levels.

While traffic volume counts are available from the City of Calgary and the City of Edmonton, they are not comprehensive in their coverage. In particular, many of the locations we observed were in suburban residential areas, where volume counts are not routinely conducted. For this reason, it was necessary for us to collect this information on our own. We consulted with the Institute of Transportation Engineers (ITE) Trip Generation Handbook for guidance on establishing local traffic volume rates.(**103**) The ITE recommends surveying at least three sites representative of the land use to be analyzed. Since we were interested in traffic volume at specific crash sites, we did not deem it necessary to collect traffic volume at multiple sites, but rather on different occasions. We planned to evaluate the reliability of our traffic volume data by comparing two traffic counts completed at approximately the same time and day of the week one or two weeks apart. We planned to do this for 10 case and 10 control sites. This would allow us to verify that the vehicle counts provided consistent results and to identify any outliers. Unfortunately, we were not able to do this due to feasibility and limited resources. In lieu, we examined the traffic counts of locations that were examined more than once in a 2-3 week period at the same time of day (± 1 hour).

Despite the limited number of sites for which City of Calgary and City of Edmonton average annual weekday traffic (AAWT) estimates are provided, we saw the utility in comparing our vehicle counts with the City estimates where this was possible; however, direct comparisons between our data and the City data proved challenging. AAWT represents the average traffic on a weekday over a 24 hour period. Our counts were conducted at a specific time, representative of the case injury time, including weekends. Given that volume varies considerably by time and day, calculating a daily average was not possible from our data. In addition, the cities each use different volume level cut-offs, and most of the sites we visited fell in the lowest categories. In order to attempt comparisons, we needed to establish low/high cut-off points for our data that were comparable with the city classifications. Given the challenges mentioned, we opted to use traffic counting method as a proxy for volume. Locations where traffic was counted in both directions were classified as low volume, and locations where counts were done in one direction per period were classified as high volume. When traffic was counted in the cyclist's direction of travel, the actual traffic count was examined and each location was individually categorized based on the number of vehicles observed. Since very few of the sites compared had high volume by the City classifications, we used the lowest classification (<11,000 vehicles per day) as the cut-off for low volume for the City data. We compared how each location was categorized using our method, with the traffic level estimated by the Cities. Using both our repeated counts and the City comparisons allowed us to gauge the robustness of the traffic volume data we collected.

3.9.3.4 Types of Locations

Observed locations were categorized on the Traffic and Cyclist Flow Data Collection Forms. Locations were described as: schools, campuses, park/recreation areas, residential, pathways, roadways, intersections, bus stops, parking lots, or "other". Since a single location could be characterized several ways, multiple response choices were permitted. Categorizing locations in this manner allowed us to examine the types of locations where people were bicycling at the time of the injury event, and how the various categories might relate to injury risk.

Some locations observed were strictly bicycle or multi-use pathways, away from roadways and motorized traffic. When a pathway was not adjacent to a roadway, traffic volume, speed limit, and average speed were not recorded, and this information was recorded as being "not applicable" on the Traffic Flow Data Collection Form. These types of locations usually consisted of a single path. As such these paths were recorded as "side 1" on the SPACES tool, and side 2 was noted as being "not applicable". Variables referring to roadway characteristics were also "not applicable" for these sites. There were 15 locations identified as pathways in Calgary, and 22 in Edmonton. It should be noted that only severely injured cases and minor injury controls could have been riding on pathways, and as such, pathways were only included in the analysis of risk factors for severe injury.

3.9.3.5 Weather Conditions

Weather and light conditions at the time of the crash were recorded as part of the CIRF bicyclist interview. We used Environment Canada Weather archives (online) to confirm the conditions and obtain the temperature at the time of each injury event.(**104**) The information was recorded in a spreadsheet and added to the bicyclist interview data.

3.9.4 Data Management

3.9.4.1 Data Entry

The CIRF research assistants entered data from the bicyclist interview in a research database designed for the CIRF study (Microsoft® Access). The interview data collected in Edmonton was sent by email to Calgary in a compressed, password protected file, where it was merged with the local data.

Study materials and data collection forms for the audits were collected by the research coordinators in Calgary and Edmonton after each observation. The research coordinator checked that the information was complete and clarified with auditors if any information was missing or unclear. The coordinator recorded the auditors' names and audit date for each observation in a spreadsheet (Microsoft® Excel). Paper copies of the data collected in Edmonton were picked up by the Calgary coordinator, who entered all of the data in a research database developed for the study (Microsoft® Access).

In both the CIRF database and the database created for the audit observations, the data entry forms were designed to look like the paper forms. The databases contained free text, checkboxes, and pre-set response choices. Free text fields were used for items such as the crash narrative and location description. Checkboxes were used when multiple response choices could be selected, such as the types of buildings present in the area. Pre-set choices were available for mutually exclusive responses, such as whether or not the bicyclist was wearing a helmet (yes or no) and the number of traffic lanes (1, 2, 3, etc.). When the data were entered in the database, a unique identifier was automatically generated and assigned to each record in the CIRF interview database, as well as in the audit database. The unique identifiers for each CIRF interview were entered in the audit database and vice-versa. Once all the data were entered into the databases, the interview and audit data were linked using the unique identifiers generated at the point of data entry. Paper copies of the interview data were stored in locked cabinets in the research offices in Edmonton and Calgary and will be retained for 7 years.

3.9.4.2 Data Cleaning

In addition to checking the paper copies of the data for completeness prior to data entry, the data were checked for accuracy once data entry was completed. This was done using queries in Microsoft® Access, and by examining graphical representations (histograms, box plots) of the data. In the event of outlying observations, the original data collection forms were re-examined. This allowed the research coordinator to rule out data entry errors.

Reasons for missing data were closely examined. Where information was missing, the research coordinator examined the data collection forms to try to identify why the information was not entered, and if it had in fact been recorded. If the information was missing because of a data entry error, this was corrected. For instances where two copies of the audit were completed (two auditors) information from one copy of the audit was used for the missing values on the second audit. For example, if observer 1 did not record the number of lanes, but observer 2 did, the response from observer 2 was used for both observations. This allowed us to minimize the number of missing variables for the SPACES and Environmental Audit Supplement tools. The same procedure was conducted for locations that were audited multiple times (with the exclusion of traffic and bicyclist counts).

3.10 Data Analysis

The following sections outline the analysis completed for each phase of the project and for each of the three study objectives. All statistical analyses were completed using STATA statistical software version 10.0.(**105**)

3.10.1 Inter-Rater Reliability of the SPACES

Inter-rater agreement was examined for locations where two auditors completed the form. Several approaches were used; 1) reliability within auditor pairs; 2) reliability by case and control status; and 3) overall reliability. For each approach, kappa (κ) statistics, a measure of chance corrected agreement, were calculated for individual items on the tool. Weighted kappa (κ_{w}) was used for ordinal responses. Land use and path characteristics were examined separately from roadway characteristics for ease of understanding. Agreement ratings were based on the criteria for agreement strength as defined by Landis and Koch (1977).(**90**) Kappa statistics less than 0.2 represented poor agreement, 0.21-0.40 fair agreement, 0.41-0.60 moderate agreement, 0.61-0.80 substantial agreement, and 0.81-1.0 represented almost perfect agreement.

3.10.2 Blinded vs. Un-Blinded SPACES Audit

When two auditors visited the same location (97 locations) at least one of them was blind to the case-control status of the site. For 28 locations in Calgary and 28 in Edmonton, one auditor was blinded. For 11 locations in Calgary and 30 in Edmonton both auditors were blinded. Since each auditor independently recorded observations, two copies of the SPACES were completed; we used data from a single copy for the analysis.

There were several considerations when choosing which auditor's data to use. Most blinded auditors had considerable training and practice with the tools before conducting observations. However, some blinded auditors had less experience administering the tools, and as such, there was potential for measurement error and resulting misclassification. On the other hand, the research coordinator (in each city) was not blinded, but had more experience using the SPACES, having visited 64% of the locations in Calgary, and 40% in Edmonton. Still, the research coordinator data may have been prone to bias given their knowledge of the case-control status of locations. Ultimately, the blinded audits were chosen as the primary observations for the analysis to minimize potential bias arising from knowledge of the status locations.

3.10.3 Tabulated Analysis

For the first study objective, to describe the characteristics of the natural and built environment of high bicycling injury risk locations, a tabulated analysis by case and control status was conducted. In addition, descriptive statistics of the study sample were summarized. Tables with counts and proportions of location and bicyclist characteristics were presented by case-control status for each of the motor-vehicle and severe outcome groups described in Chapter 4.

3.10.4 Matched Analysis

Given the choice of a matched design, it was necessary to use appropriate methods of analysis. Potential risk factors were examined by matched sets, and Mantel-Haenszel summary odds ratios and corresponding 95% confidence intervals were calculated. Subsequently, conditional logistic regression was used to examine the effect of each exposure (i.e., environmental characteristic) variable on the outcomes of interest while controlling for confounders. The analysis was adjusted for potential confounders including age, sex, bicycling faster than usual and self-reported bicyclist speed.(**7, 43, 56**)

It is important to note that the sample size in this study limited the number of potential independent variables that could be examined using conditional logistic regression. As a general guideline, it has been suggested that for logistic regression models to have good prognostic properties, the number of independent variables should not exceed 10% of the number of patients in the least frequent outcome category (in this analysis, cases).(**106**) Given our matched design, this 'rule of thumb' was applied to the number of discordant sets.(**107**) The models generated used the 10% guideline as a general rule. It has also been suggested that the rule can be relaxed, allowing for a more thorough assessment of confounding.(**108**) We adopted this approach given the importance of considering known individual risk factors for bicycle injuries, particularly age, sex, and bicyclist speed. If there were at least 17 discordant sets, each potential confounder was added to the model (individually). If any of the confounders changed the crude estimate by >15% (**108**), the confounder was kept in the model. If more than one variable changed the estimate by the 15% criterion, the one which produced the greatest change was retained.

To calculate the number of discordant sets for each environmental predictor variable a cross tabulation was done where all observations for the set were listed with case-control status. Prior to modelling with additional covariates this process was repeated to check whether missing values for the covariates affected the number of discordant sets. For some environmental predictor variables, missing values for the covariate changed the number of discordant sets so as to make it impossible (i.e., violating the 10% rule) to add the covariate to the model. A detailed example is provided in the matched analysis results section.

3.10.5 Un-Matched Analysis

We also used unconditional logistic regression by breaking the matching. Odds ratios and corresponding 95% confidence intervals were calculated. First, crude estimates were calculated for each environmental predictor. Then, using a forward selection approach, potential confounders (time, age, sex, riding faster than usual, and self-reported bicyclist speed) were added to the crude models for each environmental predictor one at a time. If a covariate changed the crude estimate by more than 15% (**108**), it was retained. Covariates were added until we did not observe any more change (>15%) in the estimates, or until the number of variables reached the maximum the model could accommodate. The 10% "rule of thumb" was relaxed, and covariates were added for up to 6-7 events per case.(**108**) The final models provided an estimate adjusted for the confounders identified as being most important for each environmental characteristic.

3.11 Variables Included in the Regression (conditional and unconditional logistic regression)

Environmental characteristics were categorized or dichotomized using criteria established by the research team. Variables from the CIRF interview were coded using the same approach as the original study. For the unconditional logistic regression, in addition to age, sex, riding faster than usual and self-reported speed, time and day were examined as potential confounders. Given the limited number of outcomes and the corresponding number of variables our models could accommodate, a dichotomous variable capturing qualitative differences in time, traffic, and light conditions was created. We started by examining the distribution of case and control crash times based on time periods used by Rifaat et al.: 1) morning peak 06:31-08:30; 2) mid-day 08:31-16:00; 3) evening peak

16:01-18:00; 4) evening 18:01-24:00; 5) night 00:01-06:30.(**71**). These time periods were then combined, and day (weekday vs. weekend) was added to the time variable. The final time/day variable (*weekdaypeak*) was coded "1" for those injured during peak time (06:31-08:30 & 16:01-18:00) on a weekday (Monday-Friday). Those injured during weekday off-peak times or on weekends were assigned a value of "0". Riding faster than usual was a dichotomous variable as well. Those who responded "yes" to the question "Were you bicycling faster than typical at the time of the crash?" were coded as "1". Self-reported bicyclist speed was dichotomized as <15 km/hr vs. ≥15 km/hr based on a previous study by Thompson et al.(**109**) Table 3.3 lists the all the risk factor variables included in the final regression analyses and describes how they were categorized.

Table 3.3 Dichotomized/Categorized Risk Factor Variable Definitions

Variable	Description
Traffic speed	≤30 km/hr versus >30 km/hr estimated average vehicle speed
Traffic volume	Number of vehicles per hour; 3 categories: 1) low (≤250 vehicles/hr); 2) medium (250-749 vehicles/hr); 3) high (≥750 vehicles/hr)
Bicyclist volume	No bicyclists observed at location vs. at least one bicyclist
Path location	For each side 3 categories: 1) within 1m of roadway; 2) between 1-3 metres; 3) >3m
Path material	For each side, continuous or slab concrete and bitumen (asphalt) versus gravel and grass.
Path/road slope	Flat versus moderate or steep slope (for each side if path).
Path/road condition	Good versus moderate, poor, or under repair (for each side if path).
Path obstructions	For each side, presence of permanent obstructions (poles, signs, trees, benches, tables, fences) versus none.
Bike lane	Marked bike lane on roadway versus no marked lane.
Roadway lanes	1-3 lanes versus 4 or more lanes.
Curb	For each side 3 categories: 1) mountable curb; 2) non-mountable; 3) no curb
Traffic control devices	Presence of traffic control devices (roundabout, speed bump, chicanes/chokers, lane narrowing, and signals) versus no traffic controls.
Crossing	Presence of crossings (zebra, signals, bridge) versus no crossings
Crossing aids	Presence of crossing aids (median, kerb extension) versus no crossing aids.
Other routes	Presence of alternate routes (lanes, path through park, no through road) versus no alternate route.
Intersections	Path-path and path-road intersection versus no intersection
Streetlights	For each side, presence of street lighting versus no street lights.
Lighting on path	For each side, whether lighting covered the path or not.
Destinations	The location provided access to services or other destinations (e.g., park, convenience store, businesses), versus no destinations.
Driveways	Presence of driveway crossovers versus no driveways.
Surveillance	Location could be observed from >75% of buildings, versus less than 75%.
Maintenance	Location gardens and verges were >75% well maintained, verses less than 75%.
Verge trees	Presence of tress along the verge, versus no trees.
Tree height	Tall or medium sized trees versus small trees.
Cleanliness	Location is clean (free of debris, garbage, graffiti etc.) versus some un-cleanliness.
Path width	Path is 150 centimetres or less, versus wider than 150 centimetres.
Age	≤14 years old vs. ≥15 years old
Bicyclist speed	<15 km/hr vs. ≥15 km/hr
Bicycling faster than usual	Bicyclist reported excessive speed at the time of the incident
Peak time	Peak time (Monday-Friday 06:31-08:30 & 16:01-18:00) versus off-peak time and weekends (Saturday and Sunday)

3.12 Sensitivity Analysis

As an exploratory analysis, we examined the possibility of using other statistical techniques for estimating the effect of environmental characteristics. We tested the use of propensity scores and summary risk scores for estimating the effect of one exposure (designated bicycle lanes) on the outcome of motor-vehicle collision. We compared the results of these adjustment methods and those from the conventional multiple logistic regression.

3.12.1 Propensity Score

The propensity score has been described as the conditional probability of exposure given an observed group of covariates.(**110, 111**) It has been suggested that using this score may be a better way to adjust for covariates and reduce bias, particularly when the number of possible covariates is large and when reducing model dimensionality is preferable.(**111, 112**)

One of the advantages of propensity scores is that they make it possible to include an exhaustive list of potential confounders into a single score for each participant. The score can then be added to a logistic regression model with the outcome just as any other covariate. Some of the literature on these methods suggests that a standard forward or backward selection process should be adopted when determining which variables to include in the score.(**112**) Others, however, argue that the number of variables one can include is irrelevant because the score is used to balance treatment (or exposure) groups rather than to make inferential statements concerning the groups.(**110, 111, 113**) To err on the side of caution, we used a combination of these approaches.

First, we included variables known to be related to bicycling injury outcomes: age, sex, and self-reported bicyclist speed. In addition, we examined whether other variables that were logically expected to be related to either the exposure or the outcome, were in fact significantly associated with the two. The variables we considered were: peak time (dichotomous: yes vs. no), previous experience bicycling at the location (dichotomous: yes vs. no), riding faster than usual (dichotomous: yes vs. no), traffic volume (categorical: low vs. medium or high), bicyclist volume (dichotomous: any vs. none), pavement (dichotomous: yes vs. no), and trip purpose (dichotomous: utilitarian vs. other). Only traffic volume and trip purpose appeared to be associated with the exposure and the outcome. As such, these variables were included in the propensity score. We also included two other covariates (peak time and riding faster than usual) in the propensity score model because these variables were shown to confound the relationship between designated bicycle lanes and motor-vehicle collisions in our multiple logistic regression.

Several approaches have been suggested for including the propensity score in logistic regression analysis.(**110, 111, 113**) These approaches are not discussed at length here; but in brief the options are: 1) to include the score directly as a probability; 2) to match subjects from the exposure groups by propensity score; and 3) to stratify the sample into groups (e.g., quintiles) based on the score.(**110, 111, 113**) Given the small sample size for this analysis, we opted to examine tertiles of the score. Two indicator variables were created capturing the middle and highest tertiles, and the lowest tertile was designated as the reference category. The logistic regression model included the outcome (motor-vehicle collision), the exposure (designated bicycle lanes), and the two indicators for propensity score tertiles. The resulting estimate was compared with the estimate obtained from the conventional multiple logistic regression where individual covariates were added to the model in a stepwise fashion.

3.12.2 Summary Risk Score

The summary risk score (SRS) was calculated based in part on the multivariate confounder score initially proposed by Miettinen and the variation of this score ("disease risk score") used by Arbogast et al. in their work on risk factors for cardiovascular disease.(**112, 114**) The approach for developing and using the SRS was quite similar to that used for the propensity score, and the advantages of using a single score to adjust for multiple confounders (e.g., reducing dimensionality of the models) still apply. The most important difference between the two approaches is how the SRS was developed. Unlike the propensity score, which was modelled based on exposure, the SRS was modelled using the outcome (motor-vehicle collision). One advantage of this approach was that it overcomes the limitations created when exposure categories (or groups) are relatively infrequent. This approach may also offer advantages in situations where the exposure is not dichotomous, although the application of a summary score in such situations is not well-studied.(**112**) Our approach mirrored Arbogast et al., where the SRS was calculated among the unexposed subjects only. This was proposed by the authors as a method of reducing bias when the exposure may be correlated with the confounders. Restricting the score model to the unexposed resulted in a minor loss of data, given that there were few (n=12) subjects exposed.

Using the same process as the propensity score model, we examined whether potential confounders were independently related to the exposure and the outcome. The covariates examined included: age, sex, self-reported bicyclist speed, riding faster than usual, time/day, traffic volume, bicyclist volume, trip purpose, and previous experience at the location. Some of these factors are already known to be risk factors for motor-vehicle collisions (age, sex, and bicyclist speed); while others were shown to be significantly related when we modelled them (time/day, trip purpose, riding faster than usual, and traffic volume). These covariates were added to a model with the outcome, and the SRS was calculated as the estimated predicted probabilities among the unexposed group.

Miettinen and Arbogast et al. have suggested that the SRS be divided into quintiles.(**112, 114**) However, in order to avoid spreading the data too thin, we used the same approach as for the propensity score and opted to examine tertiles. The lowest tertile was designated as the reference group, and indicator variables were created for the two other tertiles. The indicators were added to the model with outcome and the exposure to produce an adjusted estimate for the effect of bicycle lanes on the risk of motor-vehicle collision.

3.13 Ethical Considerations

Ethical approval from the University of Calgary Conjoint Health Research Ethics Board and the University of Alberta Health Research Ethics Board was granted as a protocol modification to the existing CIRF study approval.

Because the crash locations observed were public we deemed it necessary to develop a letter to present to concerned citizens (APPENDIX H). The letter described the purpose of the project and the observation process, specifying that the environment would not be altered or disrupted as part of the study. It was printed on official University of Calgary letterhead, and signed by the principal investigator (Dr. Brent Hagel) for the CIRF study.

3.14 Knowledge Mobilization

Knowledge mobilization (KM) was built into our research by applying the lessons about successful KM described in the Canadian Institutes of Health Research Knowledge to Action: A knowledge translation casebook.(**115**) We involved stakeholders who were in a position to effect change in the road safety environment. Several stakeholder groups including Alberta Centre for Injury Control and Research (ACICR), the Cities of Calgary and Edmonton, the Calgary and Edmonton Police Services, local and provincial bicycle groups, and national safety organizations like Safe Kids Canada were identified during the development of the study proposal. We met or corresponded with the organizations and individuals whom we deemed would be able to provide valuable feedback on the project and methods.

3.14.1 Traffic and Local Transportation

It was of primary importance to involve members of the traffic safety community and their ambassadors. The Alberta Traffic Safety Plan: Saving Lives on Alberta's Roads(**116**) has identified community mobilization as a key initiative and $4.6 million has been provided to support 16 regional traffic safety coordinator positions across the province. These traffic safety coordinators facilitate the development of traffic safety committees, assist with identification of local traffic safety issues, and strategies to address those issues and link local and regional initiatives with provincial initiatives. These coordinators are expected to build on existing partnerships and committees and to act as a traffic safety resource to local communities. We are collaborating with the ACICR, a provincial safety organization that manages traffic safety coordinator activities. Through this collaboration, we will be liaising with the Research and Data Subject Matter Expert Committee for the Alberta Traffic

Safety Plan. These links will ensure a conduit for wide dissemination of the results of our study to provincial injury prevention stakeholders.

This collaboration resulted in the establishment of significant linkages with local partners. Mr. Mike O'Conner, the Alberta Transporation and Safety Coordinator for Calgary and area, invited us to discuss our project with a local stakeholder group called "Ops and Cops" on January 21st, 2010. This group included representatives from various City of Calgary departments related to transportation operations (engineering, planning, traffic field operations, traffic signals, transit) and police officers with a variety of roles within the Calgary Police Service. The group meets monthly to discuss current traffic concerns and to jointly plan traffic safety initiatives.

Attending the Ops and Cops meeting introduced us to many stakeholders with an interest in traffic safety. Based on our feedback at the meeting, we contacted Mr. Craig Tonder, a City of Calgary engineer in transportation planning. He leads the Transportation Optimization Group that recently completed two multimodal safety reviews for the City of Calgary and has a direct interest in the study. Mr. Tonder expressed that his group would be interested in incorporating the results of the study into the next multimodal safety review and other similar reports.

Also in attendance at the Ops and Cops meeting was Ms. Julie Radke, a transportation engineer who plans for pedestrian and bicycle infrastructure changes. She and other members of the Transportation Solutions Group were interested in learning what types of collisions and location factors are related to more severe injuries. They're interested in the sight lines and environmental attributes that are potentially modifiable. If we provide this group with our results, highlighting the main risk factors we identify, they will explore what can be done to modify existing bicycle infrastucture to reduce the risk of injury. The Transportation Solutions Group plans for short, medium, and long-term countermeasures to address bicycling and pedestrian problems. The city has made a commitment to improve 20 kilometres of on-street bicycle network per year. The planning team would be in a position to consider the evidence from our project as it decides how and where to implement the 20 kilometres of yearly improvements.

3.14.2 Bicyclists

Another key group of stakeholders we sought to engage were members of the bicycling community. Many local bicycling groups exist in Calgary and Edmonton, representing and advocating for various sub-groups of bicyclists (recreational, commuters, competitors). We contacted the Alberta Bicycle Association (ABA), the provincial level bicycling governing organization, to help make our project known in the bicycle community. We met with Mr. Jeff Gruttz, a member of the ABA's Recreation and Transportation Committee. We discussed how the ABA might act on the results. Two of ABA's Recreation and Transportation Committee's goals are to protect and advocate the rights of bicyclists and to advocate and promote bicycle education.(**117**) In existence since 1973, (**118**) the group has advocacy experience and is well suited to influence infrastructure changes that would increase bicyclist safety. The group promotes a bicycle skills training program (CAN-bike) and would be motivated to consider the study results in any future updates to course content.

Mr. Gruttz helped us liase with Bike Calgary, a local organization that exists to provide information for bicyclists, offers forums for bicyclists to meet and discuss issues affecting the local bicycling community, and encourages people to choose bicycling as a form of transportation or recreational activity. Bike Calgary works to gain public acceptance for bicycling and to help develop new or improved infrastructure.(**119**) We met with the board of directors of the organization on April 12, 2010 to present the study. The board offered several possibilities for how they could use the study results. It was suggested that the findings could be integrated into educational programs the organization provides, such as a bicycle commuter course. Other possibilities mentioned were to create a brochure or list of high-risk locations in the city, or intergrate this information into existing pamphlets, and to develop a (free) workshop for bicyclists on environmental risks. As the project moves forward we will continue our discussions with Bike Calgary and move forward with some of the proposed ideas.

3.14.3 Injury Prevention and Education

In order to take the information provided from this study beyond the local context, we sought to engage injury prevention experts at the national level. Pamela Fuselli, Executive Director of Safe Kids Canada, a national injury prevention organization, agreed to partner with us to address KM activities Canada wide. These activities include the promotion of the results to Safe Kids partners through e-mail and website communication, sending targeted news release(s) from their office to key health media, promotion to partners and municipalities about the planning aspects of creating safe bicycling spaces, and dissemination of educational information to parents for the importance of instilling safe bicycling practices in, and setting positive examples for their children. We budgeted for these activities, including media outreach to the Federation of Canadian Municipalities (http://www.fcm.ca) and a press release via News Canada (http://www.newscanada.com).

In summary, the project results will be shared with identified stakeholders, such as the City of Calgary, Calgary and Edmonton Police Services, ACICR, Alberta Transportation, the ABA, and Bike Calgary, through formal written reports, presentations and interactive discussions. Our network of dissemination includes sharing our results with front line injury prevention workers through a commitment to present at the ACICR monthly teleconference series. As well, our relationship with the Executive Director of Safe Kids Canada will help us work with this organization on a national dissemination strategy for our findings. We will publish the work in peer-reviewed journals and present the information at major national (Canadian Injury Prevention and Safety Promotion Conference) and international (World Conference on Injury Prevention and Safety Promotion) conferences.

Chapter Four: Results

4.1 Reliability of the SPACES

Two observers audited 97 (35%) locations (39 in Calgary, 58 in Edmonton). As previously described, three analytic approaches were taken; 1) reliability within auditor pairs; 2) reliability by case and control status; and 3) overall reliability. The results of each approach are discussed below.

4.1.1 Reliability Within Pairs

There were 6 trained auditors in each city and auditors were not always paired with the same person. We examined inter-rater reliability for the two pairs that conducted the most audits. One pair (Pair #1: ABC & SMC) audited 14 locations in Edmonton, and another pair (Pair #2: NR & NM) audited 13 locations in Calgary. Pairings and the number of locations audited are presented in table 4.1.

Table 4.1 Auditor Pairs and Number of Audits Conducted

	Auditor 2											
Auditor 1	BJL	BR	EMT	JH	Jill	JL	JW	MN	NM	RC	SMC	Total
ABC	9	0	5	0	0	0	0	0	0	0	**14**	28
BJL	0	0	1	0	0	0	0	0	0	0	7	8
BR	0	0	0	0	0	0	0	0	0	5	0	5
EMT	0	0	0	0	0	0	0	0	0	0	7	7
JH	0	0	0	0	0	0	0	1	0	0	0	1
JL	0	0	0	0	1	0	0	0	1	0	0	2
JW	0	0	0	1	0	0	0	1	4	0	0	6
KBC	1	0	0	0	0	0	0	0	0	0	0	1
NM	0	0	0	0	0	0	0	1	0	0	0	1
NR	0	3	0	0	0	10	3	0	**13**	0	0	29
RC	0	8	0	0	0	0	0	0	0	0	0	8
SMC	1	0	0	0	0	0	0	0	0	0	0	1
Total	11	11	6	1	1	10	3	3	18	5	28	97

4.1.1.1 Land Use and Path Characteristics

There were 29 path and land use characteristics for which κ statistics could be calculated. Certain items could not be assessed for reliability (e.g., industrial land use) because these features were not identified at any of the locations audited by the pairs. Table 4.2 and 4.3 present the reliability results for pair #1 and pair #2 respectively.

Pair #1 had substantial or almost perfect agreement for 16 (57.14%) path and land use items. Four items had κ values of 1 (schools, retail, and path material). The 12 items with moderate to poor reliability had κ values ranging from 0-0.59. A κ value of 0 indicated that agreement between the two raters was not better than would have been expected by chance; however, a 0 result was only obtained where the characteristic in question was observed at a single site, and recorded by only one observer. It does not reflect true disagreement, but rather absence of the feature itself. This was the case for transport (e.g., bus stations) and offices, which both appear as “poor reliability”. This result may also be affected by the fact that some of these features can be easily confused with other types of land use such as services or retail. Pair #2 had higher agreement ratings for path and land use characteristics. Of the 27 items assessed, 25 (92.59%) had almost perfect or substantial reliability, including 19 (70.37%) that had almost perfect reliability. Kappa values ranged from 0.41 for retail, to 1.0 for several items.

Table 4.2 Pair #1: Kappa Statistics for Land Use and Path Characteristics

	Side 1			Side 2		
	Kappa	95% CI	Agreement	Kappa	95% CI	Agreement
Land use						
Transport [a]	0	n/a	Poor	0	n/a	Poor
Housing	0.69	(0.16-1.0)	Substantial	0.39	(0.0-0.88)	Fair
Office [a]	0	(0.0)	Poor	-	-	[b]
Retail	0.76	(0.25-1.0)	Substantial	1	(0.47-1.0)	Almost perfect
School	1	(0.47-1.0)	Almost perfect	1	(0.47-1.0)	Almost perfect
Services	0.76	(0.25-1.0)	Substantial	0.59	(0.12-1.0)	Moderate
Nature	0.71	(0.20-1.0)	Substantial	0.51	(0.0-1.0)	Moderate
Predominant features	0.76	(0.39-1.0)	Substantial	0.77	(0.42-1.0)	Substantial
Same features	0.86	(0.35-1.0)	Almost perfect	n/a	n/a	n/a
Path Characteristics						
Type of path	0.67	(0.22-1.0)	Substantial	0.34	(0.05-0.63)	Fair
Path location*	0.76	(0.29-1.0)	Substantial	0.77	(0.34-1.0)	Substantial
Path material	1	(0.61-1.0)	Almost perfect	0.83	(0.44-1.0)	Almost perfect
Path slope*	0.76	(0.25-1.0)	Substantial	0.6	(0.19-1.0)	Moderate
Path condition*	0.41	(0.06-0.76)	Moderate	0.52	(0.21-0.83)	Moderate
Path obstructions	0.33	(0.06-0.6)	Fair	0.17	(0.0-0.42)	Fair

[a] Only one auditor recorded the characteristic at one site
[b] Could not be examined because characteristic was not observed at any sites
*Represents weighted kappa

Table 4.3 Pair #2: Kappa Statistics for Land Use and Path Characteristics

	Side 1			Side 2		
	Kappa	95% CI	Agreement	Kappa	95% CI	Agreement
Land use						
Transport [b]	-	-	-	-	-	-
Housing	0.57	(0.02-1.0)	Moderate	0.75	(0.22-1.0)	Substantial
Office	1	(0.45-1.0)	Almost perfect	1	(0.45-1.55)	Almost perfect
Retail	0.63	(0.12-1.0)	Substantial	0.41	(-0.14-0.96)	Moderate
School	1	(0.45-1.0)	Almost perfect	1	(0.45-1.0)	Almost perfect
Services	1	(0.45-1.0)	Almost perfect	1	(0.45-1.0)	Almost perfect
Nature	1	(0.45-1.0)	Almost perfect	0.75	(0.22-1.0)	Substantial
Predominant features	1	(0.69-1.0)	Almost perfect	1	(0.67-1.0)	Almost perfect
Same features	1	(0.45-1.0)	Almost perfect	n/a	n/a	n/a
Path Characteristics						
Type of path	0.66	(0.37-0.95)	Substantial	0.75	(0.44-1.0)	Substantial
Path location*	1	(0.61-1.0)	Almost perfect	1	(0.57-1.0)	Almost perfect
Path material	1	(0.61-1.0)	Almost perfect	1	(0.55-1.0)	Almost perfect
Path slope*	1	(0.53-1.0)	Almost perfect	1	(0.49-1.0)	Almost perfect
Path condition*	0.86	(0.47-1.0)	Almost perfect	0.7	(0.33-1.0)	Substantial
Path obstructions	0.87	(0.52-1.0)	Almost perfect	0.89	(0.54-1.0)	Almost perfect

[b] Could not be examined because characteristic was not observed at any sites
*Represents weighted kappa

4.1.1.2 Roadway Characteristics

While pair #1 had slightly lower agreement on path and land use items (above), the pairs had similar reliability for roadway characteristics. Both had several items with κ values of 1 including slope, lanes, and curbs. Pair #1 had substantial to almost perfect reliability for 20 (60.60%) items. Pair #1 κ values ranged from 0.22 for cleanliness, to 1. Pair #2 had 22 (61.11%) items with substantial reliability or better. The range of values was from 0.13 for garden maintenance, to 1. For both pairs, items with lower κ values tended to be more subjective, such as the level of attractiveness for walking or bicycling, or more difficult to quantify, such as the height of trees and the number of parking spaces. Tables 4.4 and 4.5 present the results for pair #1 and pair #2. In the SPACES, some characteristics are recorded for each side, while others refer to the location in general, and are only listed for side 1.

Table 4.4 Pair #1: Kappa Statistics for Roadway Characteristics

	Side 1		**Side 2**		**Agreement (side 1, side 2)**
	Kappa	95% CI	Kappa	95% CI	
Road slope*	1	(0.41-1.0)			Almost perfect
Road condition*	0.15	(0.0-0.54)			Poor
Lanes	1	(0.63-1.0)			Almost perfect
Parking restrictions #	0.8	(0.27-1.0)	0.8	(0.25-1.0)	Substantial (both)
Curb#	0.83	(0.3-1.0)	1	(0.45-1.0)	Almost perfect (both)
Traffic control	0.86	(0.41-1.0)			Almost perfect
Crossings	0.64	(0.11-1.0)			Substantial
Crossing aids	0.65	(0.14-1.0)			Substantial
Other routes	0.69	(0.14-1.0)			Substantial
Street lights #	0.44	(0.01-0.87)	1	(0.47-1.0)	Moderate, Almost perfect
Lighting covers path #	0.48	(0.11-0.85)	0.46	(0.17-0.75)	Moderate (both)
Destinations	1	(0.47-1.0)			Almost perfect
Shop parking	0.89	(0.52-1.0)			Almost perfect
School parking	1	(0.63-1.0)			Almost perfect
Other parking	0.58	(0.27-0.89)			Moderate
Bike parking	0.89	(0.52-1.0)			Almost perfect
Driveways*	0.42	(0.11-0.73)			Moderate
Safety Characteristics					
Surveillance*	0.36	(0.05-0.67)			Fair
Garden maintenance*	0.74	(0.35-1.0)			Substantial
Verge maintenance*	0.56	(0.19-0.93)			Moderate
Verge trees* b	-	-	-	-	-
Tree height* #	0.55	(0.04-1.0)	0.43	(0-0.86)	Moderate
Aesthetic Characteristics					
Cleanliness*	0.22	(-0.25-0.69)			Fair
Views	0.72	(0.43-1.01)			Substantial
Building similarity*	0.75	(0.3-1.2)			Substantial
Attractive for walking*	0.55	(0.16-0.94)			Moderate
Attractive for bicycling*	0.44	(0.07-0.81)			Moderate
Difficult for walking* b	-	-			-
Difficult for bicycling*	0.33	(-0.08-0.74)			Fair
Continuity of path b	-	-			-
Neighbourhood legibility*	0.64	(0.21-1.07)			Substantial

b Could not be examined because characteristic was not observed at any sites
*Represents weighted kappa
#Characteristic was assessed for each side

Table 4.5 Pair #2: Kappa Statistics for Roadway Characteristics

	Side 1		Side 2		Agreement (side 1, side 2)
	Kappa	95% CI	Kappa	95% CI	
Road slope*	1	(0.37-1.0)			Almost perfect
Road condition*	0.64	(0.25-1.0)			Substantial
Lanes	1	(0.37-1.0)			Almost perfect
Parking restrictions#	1	(0.37-1.0)	0.78	(0.17-1.0)	Almost perfect, Substantial
Curb#	1	(0.37-1.0)	0.76	(0.31-1.0)	Almost perfect, Substantial
Traffic control	0.74	(0.13-1.0)			Substantial
Crossings	0.78	(0.13-1.0)			Substantial
Crossing aids	1	(0.35-1.0)			Almost perfect
Other routes	0.57	(0.0-1.0)			Moderate
Street lights #	0.75	(0.2-1.0)	0.43	(0.0-0.9)	Substantial, Moderate
Lighting covers path #	0.87	(0.46-1.0)	0.6	(0.21-0.99)	Almost perfect, Moderate
Destinations	0.53	(0.04-1.0)			Moderate
Shop parking	0.6	(0.23-0.97)			Moderate
School parking	0.45	(0.06-0.84)			Moderate
Other parking	0.45	(0.06-0.84)			Moderate
Bike parking	0.58	(0.17-0.99)			Moderate
Driveways*	0.72	(0.27-1.0)			Substantial
Safety Characteristics					
Surveillance*	0.65	(0.24-1.0)			Substantial
Garden maintenance*	0.13	(0.0-0.5)			Poor
Verge maintenance*	0.73	(0.3-1.0)			Substantial
Verge trees* #	0.77	(0.38-1.0)	0.68	(0.33-1.0)	Substantial, Substantial
Tree height* #	0.25	(0.0-0.64)	1	(0.59-1.0)	Fair, Almost perfect
Aesthetic Characteristics					
Cleanliness*	0.71	(0.26-1.0)			Substantial
Views	0.69	(0.38-1.0)			Substantial
Building similarity*	0.89	(0.42-1.0)			Almost perfect
Attractive for walking*	0.43	(0.12-0.74)			Moderate
Attractive for	0.37	(0.1-0.64)			Fair
Difficult for walking*	1	(0.45-1.0)			Almost perfect
Difficult for bicycling*	0.51	(0.16-0.86)			Moderate
Continuity of path [b]	-	-			-
Neighbourhood	0.37	(0.0-0.76)			Fair

[b] Could not be examined because characteristic was not observed at any sites
*Represents weighted kappa
#Characteristic was assessed for each side

Overall (land use, path, and roadway characteristics), pair #1 had substantial or almost perfect reliability for 59.02% of the items assessed. Pair #2 had high reliability for

74.60% of items. These results indicate good reliability for the majority of items on the tool. Not surprisingly, lower reliability was found for items that necessitated greater judgement by the auditor, as well as items that required that a number or distances be estimated (e.g., number of parking spots, height of trees).

4.1.2 Reliability by Case-Control Status

We assessed reliability by cases and controls primarily to examine whether or not observer bias may have been introduced by knowledge of the status of locations. The following sections describe the reliability results for motor-vehicle cases vs. controls and severe cases vs. controls.

4.1.2.1 Motor-Vehicle Cases and Controls

Tables 4.6 and 4.7 present the land use and path reliability results for cases and controls, respectively. The proportion of items with agreement ratings that were substantial or almost perfect was higher for controls compared with cases. Twenty-six (89.66%) items had high reliability among controls, and 19 (65.52%) did so for cases. Among cases schools on side 1 had a κ value of 0; however, this result is somewhat misleading because only one auditor recorded the characteristic at one location. Otherwise, κ ranged from 0.01 for natural features, to 1 for schools on side 2. Similarly, for controls, offices had a κ value of 0 (because of few observations). Otherwise, the range for controls was from 0.56 for natural features, to 1 for schools on side 1.

Table 4.6 Motor-Vehicle Cases: Kappa Statistics for Path and Land Use Characteristics

	Side 1			Side 2		
	Kappa	95% CI	Agreement	Kappa	95% CI	Agreement
Land use						
Transport	0.77	(0.32-1.0)	Substantial	0.64	(0.21-1.0)	Substantial
Housing	0.53	(0.06-1.0)	Moderate	0.37	(0.0-0.8)	Fair
Office	0.34	(0.0-0.69)	Fair	1	(0.53-1.0)	Almost perfect
Retail	0.75	(0.28-1.0)	Substantial	0.68	(0.21-1.0)	Substantial
School [a]	0	n/a	Poor	1	(0.53-1.0)	Almost perfect
Services	0.75	(0.28-1.0)	Substantial	0.87	(0.42-1.0)	Almost perfect
Nature	0.01	(0.00-0.46)	Poor	0.11	(0.00-0.54)	Poor
Predominant features	0.7	(0.48-0.92)	Substantial	0.6	(0.35-0.85)	Moderate
Same features	0.89	(0.44-1.0)	Almost perfect	n/a	n/a	n/a
Path Characteristics						
Type of path	0.66	(0.35-0.97)	Substantial	0.6	(0.29-0.91)	Moderate
Path location*	0.87	(0.5-1.0)	Almost perfect	0.96	(0.59-1.0)	Almost perfect
Path material	0.7	(0.35-1.0)	Substantial	0.62	(0.25-0.99)	Substantial
Path slope*	0.94	(0.57-1.0)	Almost perfect	0.84	(0.49-1.0)	Almost perfect
Path condition*	0.56	(0.23-0.89)	Moderate	0.51	(0.18-0.84)	Moderate
Path obstructions	0.69	(0.42-0.96)	Substantial	0.76	(0.49-1.0)	Substantial

[a] Only one auditor recorded the characteristic at one site
*Represents weighted kappa

Table 4.7 Motor-Vehicle Controls: Kappa Statistics for Path and Land Use Characteristics

	Side 1			Side 2		
	Kappa	95% CI	Agreement	Kappa	95% CI	Agreement
Land use						
Transport	0.82	(0.58-1.0)	Almost perfect	0.85	(0.61-1.0)	Almost perfect
Housing	0.8	(0.56-1.0)	Substantial	0.87	(0.63-1.0)	Almost perfect
Office [a]	0	n/a	Poor	0	n/a	Poor
Retail	0.73	(0.49-0.97)	Substantial	0.82	(0.58-1.0)	Almost perfect
School	1	(0.76-1.0)	Almost perfect	0.9	(0.66-1.0)	Almost perfect
Services	0.86	(0.62-1.0)	Almost perfect	0.82	(0.58-1.0)	Almost perfect
Nature	0.68	(0.44-0.92)	Substantial	0.56	(0.32-0.8)	Moderate
Predominant features	0.77	(0.63-0.91)	Substantial	0.8	(0.64-0.96)	Substantial
Same features	0.94	(0.7-1.0)	Almost perfect	n/a	n/a	n/a
Path Characteristics						
Type of path	0.82	(0.66-0.98)	Almost perfect	0.82	(0.64-1.0)	Almost perfect
Path location*	0.9	(0.7-1.0)	Almost perfect	0.88	(0.68-1.0)	Almost perfect
Path material	0.83	(0.69-0.97)	Almost perfect	0.85	(0.69-1.0)	Almost perfect
Path slope*	0.88	(0.68-1.0)	Almost perfect	0.87	(0.65-1.0)	Almost perfect
Path condition*	0.75	(0.59-0.91)	Substantial	0.77	(0.61-0.93)	Substantial
Path obstructions	0.61	(0.49-0.73)	Substantial	0.67	(0.53-0.81)	Substantial

[a] Only one auditor recorded the characteristic at one site
*Represents weighted kappa

Tables 4.8 and 4.9 present the results for cases and controls for roadway characteristics. For cases, 21 (56.76%) of the 37 items examined had high reliability; κ values ranged from 0.09 for tree height, to 0.91 for traffic lanes. For controls, κ ranged from 0.34 for cleanliness, to 0.94 for the presence of destinations. Twenty-three (60.53%) of the 38 items had substantial or almost perfect reliability. Thirteen items had moderate ratings, and 2 were fair.

Table 4.8 Motor-Vehicle Cases: Kappa Statistics for Roadway Characteristics

	Side 1		**Side 2**		**Agreement (side 1, side 2)**
	Kappa	95% CI	Kappa	95% CI	
Bike lane	0.64	(0.19-1.0)			Substantial
Road slope*	0.76	(0.39-1.0)			Substantial
Road condition*	0.18	(0.00-0.51)			Poor
Lanes	0.91	(0.58-1.0)			Almost perfect
Parking restrictions #	0.76	(0.29-1.0)	0.73	(0.24-1.0)	Substantial (both)
Curb #	0.75	(0.34-1.0)	0.71	(0.3-1.0)	Substantial (both)
Traffic control devices	0.48	(0.11-0.85)			Moderate
Crossings	0.85	(0.4-1.0)			Almost perfect
Crossing aids	0.72	(0.27-1.0)			Substantial
Other routes	0.75	(0.28-1.0)			Substantial
Street lights #	0.82	(0.37-1.0)	0	n/a	Almost perfect
Lighting covers path #	0.62	(0.27-0.97)	0.45	(0.08-0.82)	Substantial, moderate
Destinations	0.85	(0.38-1.0)			Almost perfect
Shop parking	0.72	(0.39-1.0)			Substantial
School parking	0.73	(0.32-1.0)			Substantial
Other parking	0.73	(0.4-1.0)			Substantial
Bike parking	0.59	(0.24-0.94)			Moderate
Driveways*	0.4	(0.09-0.71)			Fair
Safety Characteristics					
Surveillance*	0.24	(0.00-0.61)			Fair
Garden maintenance*	0.65	(0.26-1.0)			Substantial
Verge maintenance*	0.44	(0.11-0.77)			Moderate
Verge trees* #	0.83	(0.46-1.0)	0.89	(0.5-1.0)	Almost perfect (both)
Tree height* #	0.09	(0.00-0.42)	0.45	(0.18-0.72)	Poor, moderate
Aesthetic Characteristics					
Cleanliness*	0.23	(0.00-0.56)			Fair
Views	0.53	(0.26-0.8)			Moderate
Building similarity*	0.63	(0.14-1.0)			Substantial
Attractive for walking*	0.51	(0.18-0.84)			Moderate
Attractive for bicycling*	0.37	(0.04-0.7)			Fair
Difficult for walking*	0.45	(0.06-0.84)			Moderate
Difficult for bicycling*	0.04	(0.00-0.35)			Poor
Continuity of path [b]	-	-			-
Neighbourhood legibility*	0.14	(0.00-0.49)			Poor

[b] Could not be examined because characteristic was not observed at any sites
*Represents weighted kappa
#Characteristic was assessed for each side

Table 4.9 Motor-Vehicle Controls: Kappa Statistics for Roadway Characteristics

	Side 1		Side 2		Agreement (side 1, side 2)
	Kappa	95% CI	Kappa	95% CI	
Bike lane	0.85	(0.65-1.0)			Almost perfect
Road slope*	0.83	(0.63-1.0)			Almost perfect
Road condition*	0.71	(0.53-0.89)			Substantial
Lanes	0.9	(0.74-1.0)			Almost perfect
Parking restrictions #	0.81	(0.59-1.0)	0.73	(0.51-0.95)	Almost perfect, substantial
Curb #	0.88	(0.7-1.0)	0.75	(0.57-0.93)	Almost perfect, substantial
Traffic control	0.91	(0.73-1.0)			Almost perfect
Crossings	0.85	(0.61-1.0)			Almost perfect
Crossing aids	0.69	(0.45-0.93)			Substantial
Other routes	0.59	(0.34-0.84)			Moderate
Street lights #	0.53	(0.31-0.75)	0.6	(0.36-0.84)	Moderate (both)
Lighting covers path #	0.48	(0.3-0.66)	0.44	(0.26-0.62)	Moderate (both)
Destinations	0.94	(0.7-1.0)			Almost perfect
Shop parking	0.9	(0.72-1.0)			Almost perfect
School parking	0.88	(0.7-1.0)			Almost perfect
Other parking	0.85	(0.67-1.0)			Almost perfect
Bike parking	0.92	(0.72-1.0)			Almost perfect
Driveways*	0.71	(0.53-0.89)			Substantial
Safety Characteristics					
Surveillance*	0.5	(0.32-0.68)			Moderate
Garden maintenance*	0.5	(0.32-0.68)			Moderate
Verge maintenance*	0.64	(0.44-0.84)			Substantial
Verge trees* #	0.84	(0.64-1.0)	0.82	(0.62-1.0)	Almost perfect (both)
Tree height* #	0.58	(0.4-0.76)	0.73	(0.55-0.91)	Moderate, substantial
Aesthetic Characteristics					
Cleanliness*	0.34	(0.12-0.56)			Fair
Views	0.71	(0.57-0.85)			Substantial
Building similarity*	0.73	(0.51-0.95)			Substantial
Attractive for walking*	0.48	(0.3-0.66)			Moderate
Attractive for	0.47	(0.29-0.65)			Moderate
Difficult for walking*	0.49	(0.25-0.73)			Moderate
Difficult for bicycling*	0.48	(0.26-0.7)			Moderate
Continuity of path	0.38	(0.14-0.62)			Fair
Neighbourhood legibility*	0.52	(0.32-0.72)			Moderate

*Represents weighted kappa
#Characteristic was assessed for each side

Overall (land use, path, and roadway characteristics), there was a difference of 13% between the proportion of items with high agreement for controls and cases; 73.13% of items for controls, and 60.60% for cases. In addition to differences between motor-vehicle cases and controls, there were lower proportions of items with high reliability for motor-vehicle groups compared with severe groups.

4.1.2.2 Severe Cases and Controls

For cases, 19 (70.37%) items had high reliability. The range of κ values was from 0.41 for type of path to 1 for schools (side 1), services, path location and path slope. For controls, 25 (86.21%) items had substantial reliability or higher. Kappa values ranged from 0.31 for office land use to 0.92 for path location. Land use and path reliability results are presented in table 4.10 for cases, and 4.11 for controls.

Table 4.10 Severe Cases: Kappa Statistics for Land Use and Path Characteristics

	Side 1			Side 2		
	Kappa	95% CI	Agreement	Kappa	95% CI	Agreement
Land use						
Transport [a]	0	n/a	Poor	0	n/a	Poor
Housing	0.75	(0.2-1.0)	Substantial	0.56	(0-1)	Moderate
Office [b]	-	-	-	-	-	-
Retail	0.63	(0.1-1.0)	Substantial	0.75	(0.2-1.3)	Substantial
School	1	(0.43-1.57)	Almost perfect	0	n/a	0
Services	1	(0.43-1.57)	Almost perfect	0.63	(0.1-1.16)	Substantial
Nature	0.8	(0.25-1.35)	Substantial	0.5	(-0.05-1.05)	Moderate
Predominant features	0.76	(0.45-1.07)	Substantial	0.84	(0.39-1.29)	Almost perfect
Same features	1	(0.43-1.57)	Almost perfect	n/a	n/a	
Path Characteristics						
Type of path	0.41	(0.08-0.74)	Moderate	0.47	(0.18-0.76)	Moderate
Path location*	0.68	(0.23-1.13)	Substantial	1	(0.51-1.49)	Almost perfect
Path material	0.61	(0.26-0.96)	Substantial	0.86	(0.47-1.25)	Almost perfect
Path slope*	0.83	(0.32-1.34)	Almost perfect	1	(0.43-1.57)	Almost perfect
Path condition*	0.71	(0.34-1.08)	Substantial	0.82	(0.45-1.19)	Almost perfect
Path obstructions	0.53	(0.22-0.84)	Moderate	0.73	(0.36-1.1)	Substantial

[a] Only one auditor recorded the characteristic at one site
[b] Could not be examined because characteristic was not observed at any sites
* Represents weighed kappa

Table 4.11 Severe Controls: Kappa Statistics for Land Use and Path Characteristics

	Side 1			Side 2		
	Kappa	95% CI	Agreement	Kappa	95% CI	Agreement
Land use						
Transport	0.88	(0.66-1.0)	Almost perfect	0.9	(0.68-1.12)	Almost perfect
Housing	0.79	(0.57-1.0)	Substantial	0.85	(0.63-1.07)	Almost perfect
Office	0.31	(0.11-0.51)	Fair	0.66	(0.46-0.86)	Substantial
Retail	0.8	(0.58-1.0)	Substantial	0.78	(0.56-1)	Substantial
School	0.9	(0.68-1.12)	Almost perfect	0.92	(0.7-1.14)	Almost perfect
Services	0.81	(0.59-1.03)	Almost perfect	0.89	(0.67-1.11)	Poor
Nature	0.59	(0.37-0.81)	Moderate	0.54	(0.32-0.76)	Moderate
Predominant features	0.79	(0.67-0.91)	Substantial	0.8	(0.66-0.94)	Substantial
Same features	0.92	(0.7-1.14)	Almost perfect	n/a	n/a	0
Path Characteristics						
Type of path	0.83	(0.69-0.97)	Almost perfect	0.86	(0.72-1)	Almost perfect
Path location*	0.92	(0.74-1.1)	Almost perfect	0.87	(0.69-1.05)	Almost perfect
Path material	0.88	(0.76-1)	Almost perfect	0.86	(0.72-1)	Almost perfect
Path slope*	0.9	(0.72-1.08)	Almost perfect	0.87	(0.69-1.05)	Almost perfect
Path condition*	0.74	(0.6-0.88)	Substantial	0.74	(0.6-0.88)	Substantial
Path obstructions	0.68	(0.56-0.8)	Substantial	0.73	(0.61-0.85)	Substantial

* Represents weighted kappa

For roadway characteristics, the proportion of items with substantial or higher reliability was slightly lower than for path and land use items, but similar for cases and controls. For controls, 26 (68.42%) items had κ values above 0.60. Kappa values ranged from 0.36 for cleanliness, to 0.92 for the presence of a bicycle lane. Another item with lower reliability (0.47-0.53) was whether or not the streetlights covered the path. This item was particularly hard to assess given that most audits were conducted during the day. Items with poor, fair, or moderate reliability were the same for cases. Of the 37 items, 27 (72.96%) had substantial to almost perfect reliability. Several items including bike lanes, slope, traffic lanes, crossings, and destinations had κ values of 1. The results are presented in table 4.12 for cases and 4.13 for controls.

Table 4.12 Severe Cases: Kappa Statistics for Roadway Characteristics

	Side 1		Side 2		Agreement (side 1, side 2)
	Kappa	95% CI	Kappa	95% CI	
Bike lane	1	(0.37-1.0)			Almost perfect
Road slope*	1	(0.51-1.0)			Almost perfect
Road condition*	0.41	(0.14-0.68)			Moderate
Lanes	1	(0.61-1.0)			Almost perfect
Parking restrictions [#]	0.71	(0.26-1.0)	0.66	(0.23-1.0)	Substantial (both)
Curb [#]	0.71	(0.26-1.0)	0.73	(0.32-1.0)	Substantial (both)
Traffic control devices	0.86	(0.47-1.0)			Almost perfect
Crossings	1	(0.53-1.0)			Almost perfect
Crossing aids	1	(0.41-1.0)			Almost perfect
Other routes	0.8	(0.19-1.0)			Substantial
Street lights [#]	1	(0.43-1.0)	0.8	(0.25-1.0)	Almost perfect (both)
Lighting covers path [#]	1	(0.55-1.0)	0.87	(0.46-1.0)	Almost perfect (both)
Destinations	1	(0.43-1.0)			Almost perfect
Shop parking	0.86	(0.43-1.0)			Almost perfect
School parking	0.85	(0.36-1.0)			Almost perfect
Other parking	0.71	(0.28-1.0)			Substantial
Bike parking	0.85	(0.36-1.0)			Almost perfect
Driveways*	0.49	(0.1-0.88)			Moderate
Safety Characteristics					
Surveillance*	0.18	(0.0-0.51)			Poor
Garden maintenance*	0.29	(0.0-0.64)			Fair
Verge maintenance*	0.62	(0.25-0.99)			Substantial
Verge trees* [#]	0.76	(0.31-1.0)	0.71	(0.24-1.0)	Substantial (both)
Tree height* [#]	0.55	(0.12-0.98)	0.73	(0.32-1.0)	Moderate, substantial
Aesthetic Characteristics					
Cleanliness*	0.0	(0.0-0.26)			Poor
Views	0.65	(0.32-0.98)			Substantial
Building similarity*	0.87	(0.42-1.0)			Almost perfect
Attractive for walking*	0.38	(0.0-0.79)			Fair
Attractive for	0.25	(0.0-0.68)			Fair
Difficult for walking*	0	(0-0)			Poor
Difficult for bicycling*	0.29	(0.0-0.68)			Fair
Continuity of path [b]	-	-			-
Neighbourhood legibility*	0.62	(0.21-1.0)			Substantial

[b] Could not be examined because characteristic was not observed at any sites
* Represents weighed kappa
[#] Characteristic was assessed for each side

Table 4.13 Severe Controls: Kappa Statistics for Roadway Characteristics

	Side 1		Side 2		Agreement (side 1, side 2)
	Kappa	95% CI	Kappa	95% CI	
Bike lane	0.92	(0.74-1.0)			Almost perfect
Road slope*	0.91	(0.73-1.0)			Almost perfect
Road condition*	0.8	(0.66-0.94)			Substantial
Lanes	0.91	(0.79-1.0)			Almost perfect
Parking restrictions #	0.87	(0.71-1.0)	0.82	(0.66-0.98)	Almost perfect (both)
Curb #	0.91	(0.75-1.0)	0.8	(0.64-0.96)	Almost perfect (both)
Traffic control devices	0.88	(0.74-1.0)			Almost perfect
Crossings	0.88	(0.7-1.0)			Almost perfect
Crossing aids	0.66	(0.48-0.84)			Substantial
Other routes	0.57	(0.33-0.81)			Moderate
Street lights #	0.68	(0.46-0.9)	0.63	(0.41-0.85)	Substantial (both)
Lighting covers path #	0.53	(0.37-0.69)	0.47	(0.31-0.63)	Moderate (both)
Destinations	0.9	(0.68-1.0)			Almost perfect
Shop parking	0.84	(0.68-1.0)			Almost perfect
School parking	0.83	(0.65-1.0)			Almost perfect
Other parking	0.82	(0.66-0.98)			Almost perfect
Bike parking	0.85	(0.67-1.0)			Almost perfect
Driveways*	0.66	(0.48-0.84)			Substantial
Safety Characteristics					
Surveillance*	0.63	(0.47-0.79)			Substantial
Garden maintenance*	0.58	(0.42-0.74)			Moderate
Verge maintenance*	0.66	(0.48-0.84)			Substantial
Verge trees* #	0.86	(0.66-1.0)	0.87	(0.67-1.0)	Almost perfect (both)
Tree height* #	0.5	(0.34-0.66)	0.66	(0.5-0.82)	Moderate, substantial
Aesthetic Characteristics					
Cleanliness*	0.36	(0.18-0.54)			Fair
Views	0.71	(0.57-0.85)			Substantial
Building similarity*	0.79	(0.61-0.97)			Substantial
Attractive for walking*	0.53	(0.37-0.69)			Moderate
Attractive for	0.51	(0.35-0.67)			Moderate
Difficult for walking*	0.57	(0.35-0.79)			Moderate
Difficult for bicycling*	0.49	(0.31-0.67)			Moderate
Continuity of path	0.47	(0.25-0.69)			Moderate
Neighbourhood legibility*	0.38	(0.2-0.56)			Fair

* Represents weighted kappa
#Characteristic was assessed for each side

Overall, 76.12% of items for controls and 76.19% for cases had substantial or higher reliability. The items with lower reliability were the same for both groups, and were primarily items that required a more subjective assessment on the part of the auditor.

4.1.3 Overall Reliability

When all observer pairs were examined together, reliability was high for most items. Consistent with the results from the previous approaches, some of the more subjective observations, such as cleanliness and attractiveness had fair to moderate levels of agreement.

Sixteen (55.17%) of the 29 items in the land use and path characteristics observations had almost perfect ratings. Eleven (37.93%) were found to have substantial reliability, and 2 (6.9%) had moderate or fair reliability (Table 4.14). For roadway characteristics (Table 4.15), 25 (65.79%) items had almost perfect or substantial reliability, and 13 (34.21%) had moderate or fair ratings. The range of κ values was from 0.3 (cleanliness) to 0.91 (destinations). Aesthetic characteristics showed lower levels of agreement; 2 of the 9 items had almost perfect or substantial reliability (views and building similarity), and the remainder had moderate or fair results. The lowest κ statistic was for cleanliness (0.3).

Table 4.14 Overall Kappa Statistics for Land Use and Path Characteristics

	Side 1			Side 2		
	Kappa	95% CI	Agreement	Kappa	95% CI	Agreement
Land use						
Transport	0.83	(0.63-1.0)	Almost perfect	0.82	(0.62-1.0)	Almost perfect
Housing	0.75	(0.55-0.95)	Substantial	0.81	(0.61-1.0)	Almost perfect
Office	0.31	(0.13-0.49)	Fair	0.66	(0.48-0.84)	Substantial
Retail	0.78	(0.58-0.98)	Substantial	0.78	(0.58-0.98)	Substantial
Industry [b]	-	-	-	-	-	-
School	0.92	(0.72-1.0)	Almost perfect	0.92	(0.72-1.0)	Almost perfect
Services	0.83	(0.63-1.0)	Almost perfect	0.85	(0.65-1.0)	Almost perfect
Nature	0.61	(0.41-0.81)	Substantial	0.54	(0.34-0.74)	Moderate
Predominant features	0.79	(0.67-0.91)	Substantial	0.8	(0.68-0.92)	Almost perfect
Same features	0.91	(0.71-1.0)	Almost perfect	n/a	n/a	n/a
Path characteristics						
Type of path	0.79	(0.65-0.93)	Substantial	0.8	(0.66-0.94)	Almost perfect
Path location*	0.88	(0.72-1.0)	Almost perfect	0.88	(0.72-1.0)	Almost perfect
Path material	0.86	(0.74-0.98)	Almost perfect	0.84	(0.72-0.96)	Almost perfect
Path slope*	0.88	(0.72-1.0)	Almost perfect	0.88	(0.7-1.0)	Almost perfect
Path condition*	0.74	(0.6-0.88)	Substantial	0.75	(0.61-0.89)	Substantial
Path obstructions	0.66	(0.54-0.78)	Substantial	0.73	(0.61-0.85)	Substantial

[b] Could not be examined because characteristic was only observed at one location, on one side

*Represents weighted kappa

Table 4.15 Overall Kappa Statistics for Roadway Characteristics

	Side 1		**Side 2**		**Agreement (side 1, side 2)**
	Kappa	95% CI	Kappa	95% CI	
Bike lane	0.65	(0.43-0.87)			Substantial
Road slope*	0.82	(0.64-1.0)			Almost perfect
Road condition*	0.61	(0.45-0.77)			Substantial
Lanes	0.9	(0.76-1.0)			Almost perfect
Parking restrictions #	0.78	(0.58-0.98)	0.70	(0.48-0.92)	Substantial (both)
Curb #	0.85	(0.67-1.0)	0.74	(0.56-0.92)	Almost perfect, substantial
Traffic control	0.85	(0.67-1.0)			Almost perfect
Crossings	0.88	(0.66-1.0)			Almost perfect
Crossing aids	0.7	(0.48-0.92)			Substantial
Other routes	0.6	(0.38-0.82)			Moderate
Street lights #	0.7	(0.5-0.9)	0.65	(0.45-0.85)	Substantial (both)
Lighting covers path #	0.56	(0.4-0.72)	0.53	(0.37-0.69)	Moderate (both)
Destinations	0.91	(0.71-1.0)			Almost perfect
Shop parking	0.85	(0.69-1.0)			Almost perfect
School parking	0.83	(0.67-0.99)			Almost perfect
Other parking	0.8	(0.64-0.96)			Substantial
Bike parking	0.85	(0.69-1.0)			Almost perfect
Driveways*	0.64	(0.48-0.8)			Substantial
Safety characteristics					
Surveillance*	0.57	(0.43-0.71)			Moderate
Garden maintenance*	0.54	(0.38-0.7)			Moderate
Verge maintenance*	0.66	(0.5-0.82)			Substantial
Verge trees* #	0.85	(0.67-1.0)	0.85	(0.67-1.0)	Almost perfect (both)
Tree height* #	0.5	(0.36-0.64)	0.67	(0.53-0.81)	Moderate, substantial
Aesthetic characteristics					
Cleanliness*	0.3	(0.12-0.48)			Fair
Views	0.7	(0.58-0.82)			Substantial
Building similarity*	0.8	(0.62-0.98)			Substantial
Attractive for walking*	0.51	(0.35-0.67)			Moderate
Attractive for	0.48	(0.32-0.64)			Moderate
Difficult for walking*	0.55	(0.35-0.75)			Moderate
Difficult for bicycling*	0.46	(0.3-0.62)			Moderate
Continuity of path	0.48	(0.28-0.68)			Moderate
Neighborhood	0.41	(0.25-0.57)			Moderate

*Represents weighted kappa

Characteristic was assessed for each side

4.2 Traffic Volume Consistency

There were 10 sites where a second traffic count was conducted at the same time of day (+/- 1 hour), within 3 weeks of the first observation. The traffic counts were not always conducted by the same auditor which led to discrepancies in the counting method used (both directions, one per period, or bicyclist direction of impact). Half of the counts were conducted using the same method each time. We examined the counts at time 1 (T1) and time 2 (T2) for these 5 sites in Figure 4.1. The biggest differences in the car counts were observed at locations where the time of observation differed the most from T1 to T2. For site 2 where a difference of 117 vehicles was observed, the first audit time was from 17:04-17:35, and the second audit was from 18:32-19:02 (1.5 hours difference). This site was an arterial road which serves as an entrance to a residential community. The smallest difference (11 vehicles) was observed at site 1, where the audit times were 30 minutes apart.

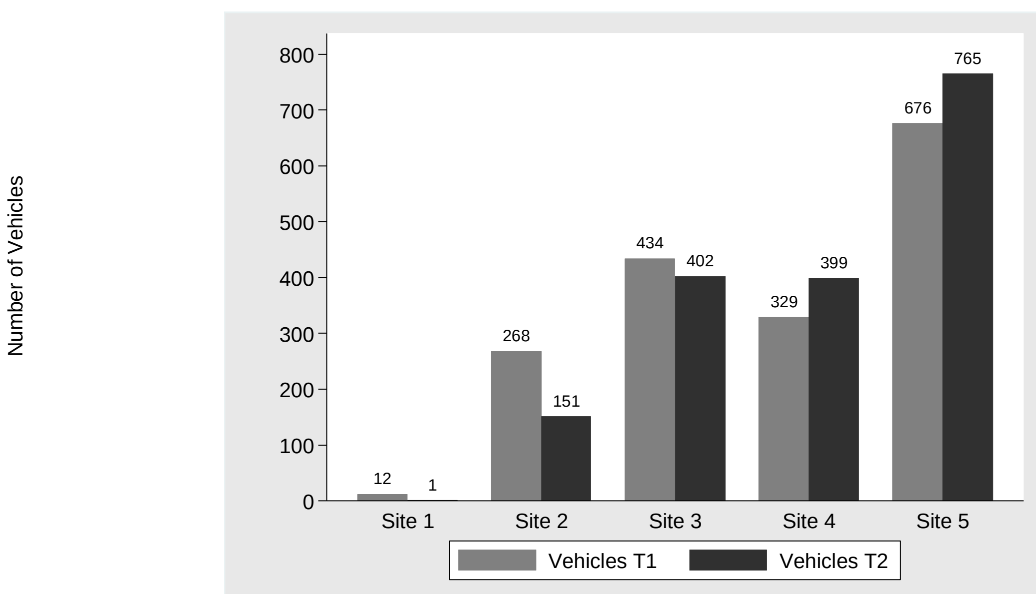


Figure 4.1 Traffic Counts Conducted on Two Occasions

There were 30 locations for which average annual weekday traffic (AAWT) estimates were available from the City of Calgary or City of Edmonton. The most recent publicly available data for Calgary were from 2008, and from 2007 for Edmonton. Each city uses different cut-offs to classify locations from low to high volume.(**120, 121**) All of the 30 locations had levels below 52 000 vehicles/day, and most locations had levels below 25 000 vehicles/day. The lowest volume level established by the City of Calgary is <11, 000 vehicles/day. We used this as the cut-off for low-volume locations. Using this cut-off, 6 locations were low volume. Of these, we classified 3 (50%) as low volume using our levels based on counting method. Of the remaining 24 locations (>11,000 vehicles/day), we classified 18 (75%) as high volume. Overall, our approach to classifying volume levels was concordant with the levels estimated by the city for 21/30 locations (70%).

Table 4.16 Average Annual Weekday Traffic (AAWT) Volume Estimates for Audited Locations

Location	AAWT	Volume level (low =≤11,000/day) (high=>11,000/day)	Traffic counting method	Observed volume (based on count method)
1 Street SW and 2nd Ave	5000	low	one per period	high
26 Ave and Crowchild Trail	10000	low	one per period	high
9 Ave SE	10000	low	both	low
James McKevitt Rd SW	11000	low	one per period	high
46 Street NW and Bowness Rd	11000	low	both	low
Bonaventure Dr SE	11000	low	both	low
Acadia Dr SE	14000	high	both	low
122 Street and Whitemud Blvd	16600	high	both	low
122 Street and 51 Ave	16600	high	one per period	high
Centre Street NE at 5600 block	20000	high	one per period	high
156 Street and 103 Ave	20300	high	both	low
68 Street and Memorial Dr NE	21000	high	one per period	high
11 Street and 11 Ave SW	21000	high	cyclist direction	high
163 Street and 107 Ave	21600	high	both	low
153 Street and Stony Plain Rd	21800	high	both	low
15 Street and 17 Ave SW	22000	high	cyclist direction	high
117 Street and 107 Ave	23200	high	one per period	high
10 Street and 17 Ave SW	24000	high	cyclist direction	high
29 Street NW	24000	high	cyclist direction	high
52 Street SE and 17 Ave	26000	high	one per period	high
116 Street and 111 Ave	27000	high	one per period	high
Centre Street NW and 78 Ave	27000	high	one per period	high
64 Ave bridge over Deerfoot	31000	high	one per period	high
14 Street and 17 Ave	31000	high	one per period	high
98 Street and 66 Ave	31300	high	both	low
111 Street and 23 Ave	31600	high	one per period	high
149 Street and Stony Plain Rd	39000	high	cyclist direction	high
149 Street and 104 Ave	39000	high	cyclist direction	high
14 Street and Memorial Drive	40000	high	one per period	high
Wayne Gretzky Dr and 106 Ave	51700	high	one per period	high

4.3 Audited Locations

In total, 274 audits were conducted at injury locations. There were 151 audits conducted in Edmonton, and 123 in Calgary. Seventy (25.55%) case sites were identified. Table 4.17 shows how many cases of each type were identified in each city.

Table 4.17 Case Distribution by City

	Case Severe	Case M-V	Case Severe/M-V	Total Cases
Calgary	16	17	0	33
Edmonton	12	19	6	37

4.4 Matching

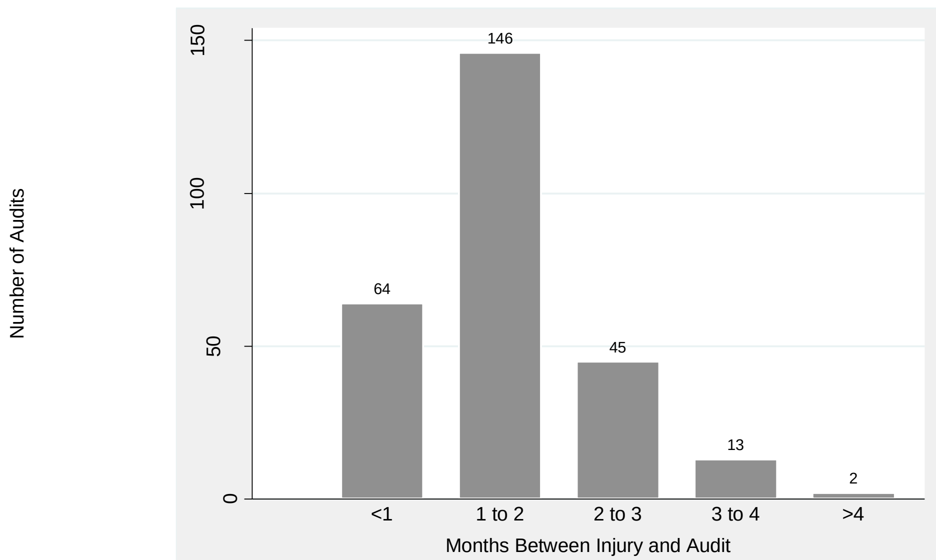
The desired case-control ratio for motor-vehicle or severely injured cases was 1:3. This ratio was achieved for 30 (49.18%) of the sets. For motor-vehicle and severely injured cases, the desired ratio was 1:6. This was not achieved for any sets. In Calgary, there were 6 incomplete sets. Three sets had one control per case, and 3 had 2 controls per case. In Edmonton, controls were only matched with cases by day. By chance however, a number of controls ended up matched on time. Table 4.18 outlines the case-control ratios (by case type) achieved with both matching criteria.

Table 4.18 Matching Ratios by Case Type

Matched case-control ratio	Number of motor-vehicle (m-v) sets	Proportion of total m-v sets (%)	Number of severe (sev) sets	Proportion of total sev sets (%)
1:1	8	25.0	7	24.14
1:2	8	25.0	6	20.69
1:3	15	46.88	15	51.72
1:4	1	3.1	1	3.45

4.5 Audit Timing

We made every effort to visit the injury locations as soon as possible after the injury event. If the bicyclist was not interviewed in person in the ED immediately after their crash (i.e., a telephone interview was conducted), the delay between the injury date and the audit was longer. Time from injury to audit ranged from 7 to 481 days. The average time between injury and audit date was 48 days, and 76.64% of audits were conducted within 2 months of the crash date (figure 4.2).



* Injury date and/or audit date was missing for 4 sites (n=270)

Figure 4.2 Time From Injury Event to Audit Date

4.6 Missing Values

A complete list of variables with missing values for the data used in the final analysis is presented in Appendix I. For motor-vehicle cases and controls, the range of missing values was from 0.42% for road slope to 11.35% for estimated average vehicle speed. The variable with the most missing values for cases was high speed limit (missing=4). The range of missing values for severe cases and controls was from 0.36% for destinations to

11.35% for high estimated average vehicle speed. The maximum number of missing observations for severe cases was 2 (traffic control devices and path width).

Because the number of missing values was low, we opted not to conduct multiple imputation analysis because we were confident that the gain associated with using this procedure would not be substantial. Given the minimal amount of data missing for cases, imputing data would not have affected the number of variables we could include in the regression models, and as such, would not be expected to make a difference in the modelling process.

In order to ensure that missing values were acknowledged in the modelling process, a complete case analysis was undertaken. With this approach, only subjects with complete data were included in the analysis. The number of variables included in any given model was determined with consideration of the number of cases missing (if any) for the exposure in question, as well as for the covariates added to the model.

4.7 Location Characteristics

The following section highlights some of the differences in location characteristics for motor-vehicle cases vs. controls and severe cases vs. controls. Table 4.19 presents location characteristics for the motor-vehicle group, and table 4.20 describes these for the severe injury group.

4.7.1 Motor-Vehicle Cases and Controls

There were 42 motor-vehicle cases and 195 motor-vehicle controls. A greater proportion of case compared with control locations had posted speed limits above 30 km/hr (80.95% vs. 70.77%), and vehicle speed was estimated to be above 30 km/hr at a greater proportion of case sites (83.33% vs. 62.05%). Also, a greater proportion of case sites were classified as having high traffic volume based on the traffic counting method used (38.1% vs. 21.03%).

Differences in the type of land use were noticed between cases and controls. While the predominant features at both case and control sites were housing, case locations had more service (11.90%) and retail (23.81%) establishments. A greater proportion of case sites were located at intersections (69.05%) compared with controls (22.56%). More control sites had the same type of predominant features on both sides compared with cases (61.54% vs. 54.76%), an indication that case sites represented more mixed land use.

Path characteristics were recorded for each side of the locations. While path types were similar for both groups, paths at case locations were located closer to the road. Seventy-one percent of side 1 paths and 59.52% of side 2 paths at case sites were located within 1 metre of the road, compared with 58.46% of side 1 and 41.03% of side 2 paths at control sites. Case sites also had a higher proportion of paths in poor condition (40.48% side 1 and 30.95% side 2) compared with controls (33.33% side 1 and 23.08% side 2). A greater proportion of case sites had permanent obstructions (e.g., poles, signs, benches, etc.) compared with controls. Over half (52.38%) of predominant paths and 35.71% of secondary paths at case sites were obstructed compared with 40.51% and 24.62% at control sites.

Overall, very few sites had designated bicycle lanes. Only 12 (5.06%) had a marked bike lane on the road. A greater proportion of roads at case sites were in poor condition (40.08%) compared with controls (32.31%), had ≥4 lanes of traffic (54.76% vs. 31.79%), crossings (59.52% vs. 39.49%), or traffic control devices (57.14% vs. 31.28%). A greater proportion of control sites had crossing aids (22.05%) such as medians or curb extensions compared with 16.67% of case sites.

A higher proportion of case locations had streetlights covering the path on side 1 (64.29%) or side 2 (71.43%) compared with controls (58.46% side 1 & 54.36% side 2). Despite having less lighting, 51.79% of control sites had high surveillance (i.e., >75% surveillance) from surrounding buildings compared with 45.24% of cases.

Aesthetic characteristics reflected the type of land use at case and control sites; a higher proportion of control sites were clean (75.90%) compared with cases (66.67%). Most sites were judged to be attractive for walking (89.23% of controls and 83.33% of cases) and bicycling (86.67% for controls and 76.19% for cases). Few sites were noted to be difficult for these activities, but cases had a higher proportion of sites that were judged difficult for bicycling compared with controls (33.33% vs. 24.62%). Most locations were deemed to be legible, which may be a reflection of the fact the people choose to cycle where it is easy to get around.

Table 4.19 Location Characteristics for Motor-Vehicle Cases and Controls

	Controls n=195	(%)	Cases n=42	(%)
Traffic characteristics				
Location speed limit				
>30 km/hr	138	(70.77)	34	(80.95)
missing	15	(7.69)	4	(9.52)
Est. Average vehicle speed				
>30 km/hr	121	(62.05)	35	(83.33)
n/a	8	(4.10)	0	(0)
missing	25	(12.82)	1	(2.38)
High traffic volume	41	(21.03)	16	(38.10)
n/a	0	(0)	0	(0)
Land use				
Type of location				
educational	21	(10.77)	5	(11.90)
intersection	44	(22.56)	29	(69.05)
bus stop	33	(16.92)	12	(28.57)
parking lot	26	(13.33)	7	(16.67)
services	8	(4.10)	2	(4.76)
bridge	1	(0.51)	0	(0)
river	1	(0.51)	0	(0)
commercial	6	(3.08)	5	(11.90)
roadway	121	(62.05)	34	(80.95)
residential	143	(73.33)	27	(64.29)
park	54	(27.69)	6	(14.29)
pathway	35	(17.95)	8	(19.05)
Predominant feature (side 1)				
transport	6	(3.08)	1	(2.38)
housing	114	(58.46)	17	(40.48)
offices	3	(1.54)	2	(4.76)
convenience	5	(2.56)	2	(4.76)
retail	7	(3.59)	10	(23.81)
industrial	1	(0.51)	0	(0)
schools	16	(8.21)	1	(2.38)
services	9	(4.62)	5	(11.90)
nature	34	(17.44)	4	(9.52)
Predominant feature (side 2)				
transport	7.00	(3.59)	0.00	(0)
housing	134	(68.72)	26	(61.90)
offices	1	(0.51)	0	(0)
convenience	1	(0.51)	1	(2.38)
retail	7	(3.59)	8	(19.05)

	Controls n=195	(%)	Cases n=42	(%)
industrial	1	(0.51)	1	(2.38)
schools	2	(1.03)	2	(4.76)
services	11	(5.64)	3	(7.14)
nature	31	(15.90)	1	(2.38)
Same predominant feature	120	(61.54)	23	(54.76)
Path characteristics (side 1)				
Path type				
no path	19	(9.74)	5	(11.90)
footpath	137	(70.26)	30	(71.43)
shared w/ markings	11	(5.64)	1	(2.38)
shared no markings	28	(14.36)	6	(14.29)
Location				
within 1m of road	114	(58.46)	30	(71.43)
btw 1-3m of road	33	(16.92)	6	(14.29)
>3m from road	28	(14.36)	1	(2.38)
n/a	19	(9.74)	5	(11.90)
missing	1	(0.51)	0	(0)
Material				
concrete/bricks	173	(88.72)	37	(88.10)
gravel/grass	2	(1.03)	0	(0)
n/a	19	(9.74)	5	(11.90)
missing	1	(0.51)	0	(0)
Sloped path	22	(11.28)	4	(9.52)
n/a	19	(9.74)	5	(11.90)
Poor Condition	65	(33.33)	17	(40.48)
n/a	19	(9.74)	5	(11.90)
Any obstructions	79	(40.51)	22	(52.38)
n/a	19	(9.74)	5	(11.90)
Path characteristics (side 2)				
Path type				
no path	62	(31.79)	8	(19.05)
footpath	110	(56.41)	26	(61.90)
shared w markings	4	(2.05)	1	(2.38)
shared no markings	16	(8.21)	6	(14.29)
n/a	3	(1.54)	0	(0)
missing	0	(0)	1	(2.38)
Location				
within 1m of road	80	(41.03)	25	(59.52)
btw 1-3m of road	32	(16.41)	8	(19.05)
>3m from road	17	(8.72)	0	(0)
n/a	65	(33.33)	8	(19.05)
missing	1	(0.51)	1	(2.38)
Material				

	Controls n=195	(%)	Cases n=42	(%)
concrete/bricks	127	(65.13)	34	(80.95)
gravel/grass	2	(1.03)	0	(0)
n/a	65	(33.33)	8	(19.05)
missing	1	(0.51)	0	(0)
Sloped path	14	(7.18)	3	(7.14)
n/a	65	(33.33)	8	(19.05)
Poor condition	45	(23.08)	13	(30.95)
n/a	65	(33.33)	8	(19.05)
Any obstructions	48	(24.62)	19	(45.24)
n/a	65	(33.33)	8	(19.05)
Roadway characteristics				
Designated bicycle lane	8	(4.10)	4	(9.52)
n/a	0	(0)	0	(0)
missing	3	(1.54)	1	(2.38)
Sloped roadway	25	(12.82)	4	(9.52)
n/a	0	(0)	0	(0)
missing	1	(0.51)	0	(0)
Poor road condition	63	(32.31)	17	(40.48)
n/a	0	(0)	0	(0)
≥4 lanes of traffic	62	(31.79)	23	(54.76)
n/a	0	(0)	0	(0)
missing	4	(2.05)	0	(0)
Traffic control devices	61	(31.28)	24	(57.14)
n/a	0	(0)	0	(0)
missing	4	(2.05)	0	(0)
Crossings (y)	77	(39.49)	25	(59.52)
n/a	0	(0)	0	(0)
missing	3	(1.54)	1	(2.38)
Crossing aids (y)	43	(22.05)	7	(16.67)
n/a	0	(0)	0	(0)
missing	3	(1.54)	0	(0)
Safety characteristics				
Lighting over path (side 1)	114	(58.46)	27	(64.29)
n/a	47	(24.10)	10	(23.81)
missing	1	(0.51)	0	(0)
Lighting over path (side 2)	106	(54.36)	30	(71.43)
n/a	46	(23.59)	5	(11.90)
missing	1	(0.51)	0	(0)
Driveways	126	(64.62)	28	(66.67)
missing	0	(0)	0	(0)
High surveillance	101	(51.79)	19	(45.24)
n/a	5	(2.56)	0	(0)

	Controls n=195	(%)	Cases n=42	(%)
Aesthetic characteristics				
High garden maintenance	113	(57.95)	24	(57.14)
n/a	10	(5.13)	2	(4.76)
missing	2	(1.03)	0	(0)
> 1 tree/block (side 1)	103	(52.82)	25	(59.52)
n/a	53	(27.18)	10	(23.81)
missing	4	(2.05)	1	(2.38)
Tall trees (side 1)	163	(83.59)	37	(88.10)
n/a	24	(12.31)	2	(4.76)
missing	0	(0)	1	(2.38)
>1 tree/block (side 2)	105	(53.85)	25	(59.52)
n/a	60	(30.77)	10	(23.81)
missing	3	(1.54)	1	(2.38)
Tall trees (side 2)	164	(84.10)	33	(78.57)
n/a	21	(10.77)	5	(11.90)
missing	0	(0)	2	(4.76)
Clean	148	(75.90)	28	(66.67)
Similar building	126	(64.62)	22	(52.38)
n/a	9	(4.62)	0	(0)
missing	2	(1.03)	0	(0)
Attractive for walking	174	(89.23)	35	(83.33)
Difficult for walking	16	(8.21)	4	(9.52)
Attractive for bicycling	169	(86.67)	32	(76.19)
Difficult for bicycling	48	(24.62)	14	(33.33)
Legible	133	(68.21)	29	(69.05)
missing	3	(1.54)	0	(0)

4.7.2 Severe Cases and Controls

There were 34 severe cases and 240 corresponding controls. Speed limit and traffic volume were similar for the groups; however, a higher proportion of severe case sites were observed to have high estimated vehicle speed compared with controls (64.71% vs. 55.83%). More control sites had low/no cyclist volume compared with cases (28.75% vs. 20.59%).

As with the motor-vehicle groups, most severe case and control locations had housing as the predominant feature. However, a higher proportion of severe control sites had schools (7.08%) or natural features (24.17%) compared with cases (2.94% and 17.65% respectively).

A slightly higher proportion of paths at case sites compared with controls were shared pathways with markings. For the predominant path, 17.65% of case and 10.83% of control paths were marked, and 11.76% and 5.42% of secondary case and control paths, respectively were marked. Path distances and materials were similar, but case sites had a higher proportion of paths on an incline, and in poor condition.

Case sites also had a higher proportion of roads in poor condition than controls (41.18% vs. 27.5%), and a higher proportion of sites with ≥4 lanes of traffic (44.12% vs. 29.17%). A greater proportion of control sites had a mountable curb (51.25% side 1 and 2) compared with cases (41.18% side 1 and 32.35% side 2), or traffic control devices (55.42% vs. 44.12%).

There were noticeable differences in the safety characteristics of severe case and control locations. A high proportion of control sites had lighting over the path on side 1 or side 2 (53.75% and 52.5%, respectively) compared with case sites (44.12% and 38.24%, respectively). Also, 48.33% of control sites and 29.422% of case sites had high surveillance.

The proportion of well-maintained gardens and verges was higher for controls than cases, but a higher proportion of case sites had >1 tree per block, and had tall trees. Both groups had similar proportions of sites judged to be attractive for walking and bicycling, and difficulty ratings were also similar. A slightly higher proportion of case sites compared with controls were observed to have continuous paths (97.06% vs. 87.5%).

Table 4.20 Location Characteristics for Severe Cases and Controls

	Controls n=240	(%)	Cases n=34	(%)
Pathway only (no road)	30	(12.5)	7	(20.59)
Traffic characteristics				
Location speed limit				
>30 km/hr	151	(62.92)	21	(61.76)
n/a	30	(12.5)	7	(20.59)
missing	18	(7.5)	1	(2.94)
Est. Average vehicle speed				
>30 km/hr	134	(55.83)	22	(64.71)
n/a	38	(15.83)	7	(20.59)
missing	25	(10.42)	1	(2.94)
High traffic volume	48	(20)	9	(26.47)
n/a	30	(12.5)	7	(20.59)
No cyclists	69	(28.75)	7	(20.59)
Land use				
Type of location				
educational	26	(10.83)	1	(2.94)
intersection	63	(26.25)	10	(29.41)
bus stop	40	(16.67)	5	(14.71)
parking lot	30	(12.5)	4	(11.76)
services	11	(4.58)	0	(0)
bridge	2	(0.83)	0	(0)
river	1	(0.42)	1	(2.94)
commercial	12	(5)	1	(2.94)
roadway	133	(55.42)	22	(64.71)
residential	157	(65.42)	21	(61.76)
park	77	(32.08)	12	(35.29)
pathway	59	(24.58)	13	(38.24)
Predominant feature (side 1)				
transport	9	(3.75)	1	(2.94)
housing	122	(50.83)	15	(44.12)
offices	3	(1.25)	2	(5.88)
convenience	6	(2.5)	1	(2.94)
retail	12	(5)	5	(14.71)
industrial	1	(0.42)	0	(0)
schools	17	(7.08)	1	(2.94)
services	12	(5)	3	(8.82)
nature	58	(24.17)	6	(17.65)
Predominant feature (side 2)				
transport	7	(2.92)	1	(2.94)
housing	149	(62.08)	17	(50)

		Controls n=240	(%)	Cases n=34	(%)
	offices	0	(0)	1	(2.94)
	convenience	2	(0.83)	0	(0)
	retail	11	(4.58)	5	(14.71)
	industrial	2	(0.83)	0	(0)
	schools	4	(1.67)	0	(0)
	services	14	(5.83)	0	(0)
	nature	51	(21.25)	10	(29.41)
Same predominant feature		155	(64.58)	21	(61.76)
Path characteristics (side 1)					
Path type					
	no path	21	(8.75)	3	(8.82)
	footpath	154	(64.17)	20	(58.82)
	shared w/ markings	26	(10.83)	6	(17.65)
	shared no markings	39	(16.25)	5	(14.71)
Location					
	within 1m of road	128	(53.33)	16	(47.06)
	btw 1-3m of road	33	(13.75)	7	(20.59)
	>3m from road	54	(22.5)	8	(23.53)
	n/a	21	(8.75)	3	(8.82)
	missing	4	(1.67)	0	(0)
Material					
	concrete/bricks	211	(87.92)	30	(88.24)
	gravel/grass	7	(2.92)	1	(2.94)
	n/a	21	(8.75)	3	(8.82)
	missing	1	(0.42)	0	(0)
Sloped path		35	(14.58)	7	(20.59)
	n/a	21	(8.75)	3	(8.82)
Poor condition		84	(35)	16	(47.06)
	n/a	21	(8.75)	3	(8.82)
Any obstructions		103	(42.92)	13	(38.24)
	n/a	21	(8.75)	3	(8.82)
Path characteristics (side 2)					
Path type					
	no path	68	(28.33)	7	(20.59)
	footpath	128	(53.33)	14	(41.18)
	shared w/ markings	13	(5.42)	4	(11.76)
	shared no markings	24	(10)	4	(11.76)
	n/a	6	(2.5)	5	(14.71)
	missing	1	(0.42)	0	(0)
Location					
	within 1m of road	93	(38.75)	12	(35.29)
	btw 1-3m of road	36	(15)	4	(11.76)
	>3m from road	32	(13.33)	6	(17.65)

		Controls n=240	(%)	Cases n=34	(%)
	n/a	74	(30.83)	12	(35.29)
	missing	5	(2.08)	0	(0)
Material					
	concrete/bricks	157	(65.42)	22	(64.71)
	gravel/grass	8	(3.33)	0	(0)
	n/a	74	(30.83)	12	(35.29)
	missing	1	(0.42)	0	(0)
Sloped path		22	(9.17)	5	(14.71)
	n/a	74	(30.83)	12	(35.29)
Poor condition		63	(26.25)	9	(26.47)
	n/a	74	(30.83)	12	(35.29)
Any obstructions		64	(26.67)	9	(26.47)
	n/a	74	(30.83)	12	(35.29)
Roadway characteristics					
Designated bicycle lane		11	(4.58)	1	(2.94)
	n/a	30	(12.5)	7	(20.59)
	missing	3	(1.25)	1	(2.94)
Poor road condition		66	(27.5)	14	(41.18)
	n/a	30	(12.5)	7	(20.59)
≥ 4 lanes of traffic		70	(29.17)	15	(44.12)
	n/a	30	(12.5)	7	(20.59)
	missing	4	(1.67)	0	(0)
Mountable curb (side 1)		123	(51.25)	14	(41.18)
	n/a	50	(20.83)	8	(23.53)
	missing	2	(0.83)	0	(0)
Mountable curb (side 2)		123	(51.25)	11	(32.35)
	n/a	54	(22.5)	12	(35.29)
	missing	1	(0.42)	0	(0)
Traffic control devices		133	(55.42)	15	(44.12)
	n/a	30	(12.5)	7	(20.59)
	missing	2	(0.83)	2	(5.88)
Crossings (y)		88	(36.67)	14	(41.18)
	n/a	30	(12.5)	7	(20.59)
	missing	3	(1.25)	1	(2.94)
Crossing aids (y)		44	(18.33)	6	(17.65)
	n/a	16	(6.67)	0	(0)
	missing	2	(0.83)	1	(2.94)
Curb cuts		127	(52.92)	20	(58.82)
Safety characteristics					
Lighting over path (side 1)		129	(53.75)	15	(44.12)
	n/a	75	(31.25)	12	(35.29)
	missing	3	(1.25)	0	(0)
Lighting over path (side 2)		126	(52.5)	13	(38.24)

		Controls n=240	(%)	Cases n=34	(%)
	n/a	68	(28.33)	12	(35.29)
	missing	4	(1.67)	0	(0)
Driveways		141	(58.75)	16	(47.06)
	missing	1	(0.42)	0	(0)
High surveillance		116	(48.33)	10	(29.41)
	n/a	19	(7.92)	5	(14.71)
Aesthetic characteristics					
High garden maintenance		133	(55.42)	15	(44.12)
	n/a	20	(8.33)	1	(2.94)
	missing	2	(0.83)	0	(0)
High verge maintenance		47	(19.58)	4	(11.76)
	n/a	138	(57.5)	15	(44.12)
	missing	1	(0.42)	0	(0)
>1 tree/block (side 1)		127	(52.92)	20	(58.82)
	n/a	65	(27.08)	8	(23.53)
	missing	5	(2.08)	1	(2.94)
Tall trees (side 1)		203	(84.58)	32	(94.12)
	n/a	24	(10)	2	(5.88)
	missing	3	(1.25)	0	(0)
>1 tree/block (side 2)		127	(52.92)	21	(61.76)
	n/a	73	(30.42)	8	(23.53)
	missing	4	(1.67)	1	(2.94)
Tall trees (side 2)		202	(84.17)	31	(91.18)
	n/a	25	(10.42)	1	(2.94)
	missing	3	(1.25)	0	(0)
Clean		181	(75.42)	28	(82.35)
Similar buildings		141	(58.75)	17	(50)
	n/a	29	(12.08)	5	(14.71)
	missing	3	(1.25)	0	(0)
Attractive for walking		216	(90)	30	(88.24)
Difficult for walking		20	(8.33)	4	(11.76)
Attractive for bicycling		208	(86.67)	27	(79.41)
Difficult for bicycling		66	(27.5)	12	(35.29)
Continuity		210	(87.5)	33	(97.06)
	n/a	1	(0.42)	0	(0)
	missing	7	(2.92)	0	(0)

4.8 Crash and Bicyclist Characteristics

The following section highlights some of the differences in crash and bicyclist characteristics between motor-vehicle cases vs. controls, and severe cases vs. controls.

These data were extracted from the bicyclist interview. Table 4.21 presents characteristics for motor-vehicle cases and controls, and table 4.22 presents the same for severe cases and controls.

4.8.1 Motor-Vehicle Cases and Controls

Both case and control groups had a higher proportion of males (69.05% and 75.38%, respectively). A much higher proportion of controls compared with cases were younger than 13 years (41.03% vs. 14.29%), and a higher proportion of cases were >18 years old (66.67% vs. 41.54%). A higher proportion of controls had post-secondary education (maternal education level if <14 years old) (72.31%) compared with cases (57.14%).

A greater proportion of cases compared with controls were bicycling during the morning (06:31-08:30) and evening (16:01-18:00) peak periods (AM 21.43% vs. 8.21%; PM 33.33% vs. 22.05%). These represent the hours where people commute to work or school. This is reflected in that 45.24% of cases and only 17.95% of controls reported that they were commuting at the time of the crash. Another factor that may reflect this is that 88.10% of cases and 68.21% of controls said that they had cycled at the location of the crash more than 3 times before. In addition, a lower proportion of cases than controls reported that they were riding with others at the time (23.81% vs. 51.28%). All of these seem to indicate that motor-vehicle events occur during peak hours, and involve those bicycling for transportation; it also highlights that these factors need to be accounted for in examining risk factors for motor-vehicle collisions.

Only 42.86% of cases compared with 71.28% of controls reported wearing a helmet at the time of the crash. The use of reflective clothing and other safety articles was low overall. Sixteen percent of cases and 12.31% of controls reported wearing reflective clothing, and only 2.5% of cases and controls used safety articles. The proportion of bicyclists wearing light coloured clothing on the upper and lower body was similar for both groups; approximately 40% wore light colours on the upper body, and between 30-40% for the lower body.

4.8.1.1 Injuries

Cases suffered a higher proportion of head injuries, including concussions, minor head injuries, and intracranial injuries, than controls (16.67% vs. 7.18%). Controls suffered a higher proportion of fractures (36.92%), and dislocations or sprains/strains (9.23%). Controls tended to injure the upper extremities (52.31%), while a higher proportion of cases suffered lower extremity injuries (38.10%). Also, a higher proportion of cases than controls suffered injuries to multiple body regions (11.90% vs. 3.59%). Perhaps surprisingly, 5% of cases left the emergency department prior to being seen by a physician.

Table 4.21 Crash and Bicyclists Characteristics for Motor-Vehicle Cases and Controls

	Controls n=195	(%)	Cases n=42	(%)
Crash circumstances				
Weekday	144	(73.85)	33	(78.57)
missing	3	(1.54)	0	(0)
Time of day				
06:31-08:30	16	(8.21)	9	(21.43)
08:31-16:00	67	(34.36)	7	(16.67)
16:01-18:00	43	(22.05)	14	(33.33)
18:01-24:00	66	(33.85)	11	(26.19)
00:01-06:30	3	(1.54)	1	(2.38)
Surface condition				
dry	142	(72.82)	35	(83.33)
wet	2	(1.03)	1	(2.38)
slush	0	(0)	1	(2.38)
loose	24	(12.31)	4	(9.52)
muddy	2	(1.03)	0	(0)
hole/bump	20	(10.26)	0	(0)
don’t know	3	(1.54)	0	(0)
missing	2	(1.03)	1	(2.38)
Bicyclist fault	143	(73.33)	18	(42.86)
don’t know	19	(9.74)	1	(2.38)
Missing	0	(0)	1	(2.38)
Bicyclist high speed (>25km/hr)	24	(12.31)	5	(11.90)
don’t know	38	(19.49)	1	(2.38)
missing	2	(1.03)	1	(2.38)
Reason bicycling				
going to/from work	22	(11.28)	15	(35.71)
visiting friends/family	13	(6.67)	3	(7.14)
going to/from party	1	(0.51)	0	(0)
fun/recreation	128	(65.64)	16	(38.10)
going to/from shopping	14	(7.18)	4	(9.52)
going to/from sports	3	(1.54)	0	(0)
going to/from school	13	(6.67)	4	(9.52)
missing	1	(0.51)	0	(0)
Previously cycled at location	167	(85.64)	40	(95.24)
missing	0	(0)	1	(2.38)
Riding with others	100	(51.28)	10	(23.81)
Regular bicyclist	153	(78.46)	37	(88.10)
missing	0	(0)	1	(2.38)
Protective equipment				
Helmet	139	(71.28)	18	(42.86)

	Controls n=195	(%)	Cases n=42	(%)
missing	0	(0)	1	(2.38)
Reflective clothing	24	(12.31)	7	(17.67)
don't know	3	(1.54)	0	(0)
missing	0	(0)	1	(2.38)
Safety articles	5	(2.56)	1	(2.38)
don't know	3	(1.54)	0	(0)
missing	2	(1.03)	1	(2.38)
Front upper body light	81	(41.54)	18	(42.86)
don't know	27	(13.85)	3	(7.14)
missing	0	(0)	1	(2.38)
Lower body light	59	(30.26)	14	(33.33)
don't know	18	(9.23)	0	(0)
missing	0	(0)	1	(2.38)
Bicyclist characteristics				
Males	147	(75.38)	29	(69.05)
Age				
<13 years	80	(41.03)	6	(14.29)
13-17 years	34	(17.44)	8	(19.05)
>18 years	81	(41.54)	28	(66.67)
Alcohol (if ≥14 years old)	13	(12.26)	2	(5.71)
missing	4	(3.77)	1	(2.86)
Drugs (if ≥14 years old)	2	(1.89)	4	(11.43)
refused to answer	5	(4.72)	0	(0)
missing	4	(3.77)	1	(2.86)
Post-secondary education	141	(72.31)	24	(57.14)
don't know	7	(3.59)	1	(2.38)
missing	4	(2.05)	1	(2.38)
High income (>$70,000/yr)	85	(43.59)	17	(40.48)
don't know	33	(16.92)	3	(7.14)
missing	33	(16.92)	5	(11.90)
Previous bicycling injury	65	(33.33)	10	(23.81)
n/a	112	(57.44)	28	(66.67)
missing	1	(0.51)	2	(4.76)
Injury details				
Head injury	14	(7.18)	7	(16.67)
n/a (lwbs*)	2	(1.03)	2	(4.76)
missing	1	(0.51)	0	(0)
Body region injured				
scalp/skull/head	34	(17.44)	4	(9.52)
spine	0	(0)	0	(0)
trunk	9	(4.62)	1	(2.38)
upper extremity	102	(52.31)	14	(33.33)
lower extremity	40	(20.51)	16	(38.10)

	Controls n=195	(%)	Cases n=42	(%)
multiple locations	7	(3.59)	5	(11.90)
no injury identified (lwbs*)	2	(1.03)	2	(4.76)
missing	1	(0.51)	0	(0)
Type of injury				
fracture	72	(36.92)	11	(26.19)
superficial	50	(25.64)	12	(28.57)
head injury	13	(6.67)	4	(9.52)
dislocation/sprain/strain	18	(9.23)	3	(7.14)
open wound/laceration	38	(19.49)	10	(23.81)
internal organ injury	1	(0.51)	0	(0)
dental injury	0	(0)	0	(0)
no injury identified (lwbs*)	2	(1.03)	2	(4.76)
missing	1	(0.51)	0	(0)

*Left without being seen

4.8.2 Severe Cases and Controls

Over 70% of severe cases and controls were males. A higher proportion of severe controls compared with cases were younger than 13 years (37.08% vs. 17.65%), while a higher proportion of cases were older than 18 years (76.47% vs. 44.17%). A higher proportion of controls than cases reported having post-secondary education (maternal education if <14 years old) (73.33% vs. 55.88). Nearly 20% of cases reported drinking alcohol prior to the crash, while only 7.25% of controls reported doing so. Also, 14.81% of cases reported recreational drug use before the crash, while the proportion of controls that reported doing so was less than 2%.

A higher proportion of cases than controls reported that the surface they were bicycling on had holes or bumps (14.71% vs. 7.92%). Controls appeared to have more experience bicycling at the location of the injury event, 87.08% of controls reported having bicycled at the location of the crash more than 3 times before, compared with 73.53% of cases.

Motor-vehicles were involved in a higher proportion of severe injury events than controls (20.59% vs. 16.25%), yet the proportion of motor-vehicle events among the severe injury group was still relatively low. Most severe injuries occurred in single person events (61.76%). There were few differences in the proportion of cases and controls bicycling for various reasons; roughly 15% were bicycling to/from work, 6% visiting friends or family, and over 60% were bicycling for personal recreation.

Helmet use was lower in cases than controls. Fifty-five percent of cases wore a helmet, compared with 71.25% of controls. The use of additional safety articles was low; only 12 (5%) controls reported using safety articles. The use of light coloured clothing on the upper body ranged from 40.83% for controls to 52.94% for cases, and the use of light clothing on the lower body was approximately 30% for both groups.

4.8.2.1 Injuries

The proportion of head injuries in cases and controls was similar. Cases suffered a higher proportion of fractures (73.53%), while controls suffered a higher proportion of superficial injuries (27.92%), dislocation/sprains/strains (9.17%) and open wounds or lacerations (21.67%). Cases had a higher proportion of injuries to the head/face (17.65%), and lower extremities (32.35%), while controls mostly suffered injuries to the upper extremities (50%). Only 4 (1.67%) controls left the emergency department before being seen by a physician.

Table 4.22 Crash and Bicyclist Characteristics for Severe Cases and Controls

	Controls n=240	(%)	Cases n=34	(%)
Crash circumstances				
Week day	181	(75.42)	24	(70.59)
missing	2	(0.83)	1	(2.94)
Time of day				
06:31:08:30	25	(10.42)	3	(8.82)
08:31-16:00	75	(31.25)	11	(32.35)
16:01-18:00	56	(23.33)	8	(23.53)
18:01-24:00	80	(33.33)	11	(32.35)
00:01-06:30	4	(1.67)	1	(2.94)
Surface condition				
dry	173	(72.08)	22	(64.71)
wet	7	(2.92)	1	(2.94)
slush	1	(0.42)	0	(0)
loose	30	(12.5)	5	(14.71)
muddy	3	(1.25)	0	(0)
hole/bump	19	(7.92)	5	(14.71)
don't know	2	(0.83)	1	(2.94)
missing	5	(2.08)	0	(0)
Crash type				
single person event	139	(57.92)	21	(61.76)
impact with person/object	58	(24.17)	6	(17.65)
motor-vehicle involvement	39	(16.25)	7	(20.59)
don't know	3	(1.25)	0	(0)
missing	1	(0.42)	0	(0)
Bicyclist high speed (>25km/hour)	27	(11.25)	3	(8.82)
don't know	42	(17.5)	5	(14.71)
missing	3	(1.25)	0	(0)
Reason bicycling				
going to/from work	37	(15.42)	5	(14.71)
visiting friends/family	16	(6.67)	2	(5.88)
going to/from party	1	(0.42)	0	(0)
fun/recreation	150	(62.5)	23	(67.65)
going to/from shopping	15	(6.25)	3	(8.82)
going to/from sports	3	(1.25)	0	(0)
going to/from school	16	(6.67)	1	(2.94)
missing	2	(0.83)	0	(0)
Previously cycled at location	209	(87.08)	25	(73.53)
missing	1	(0.42)	0	(0)
Riding with others	113	(47.08)	15	(44.12)

	Controls n=240	(%)	Cases n=34	(%)
Protective equipment				
Helmet	171	(71.25)	19	(55.88)
missing	1	(0.42)	0	(0)
Reflective clothing	31	(12.92)	4	(11.76)
don't know	4	(1.67)	0	(0)
missing	1	(0.42)	0	(0)
Safety articles	12	(5)	0	(0)
don't know	4	(1.67)	0	(0)
missing	4	(1.67)	0	(0)
Front upper body light	98	(40.83)	18	(52.94)
don't know	29	(12.08)	3	(8.82)
missing	1	(0.42)	0	(0)
Lower body light	71	(29.58)	12	(35.29)
don't know	18	(7.5)	1	(2.94)
missing	1	(0.42)	0	(0)
Bicyclist characteristics				
Male	176	(73.33)	24	(70.59)
Age				
<13 years	89	(37.08)	6	(17.65)
13-17 years	45	(18.75)	2	(5.88)
≥18 years	106	(44.17)	26	(76.47)
Alcohol (if age ≥ 14 years)	10	(7.25)	5	(18.52)
missing	5	(3.62)	0	(0)
Drugs (if age ≥ 14 years)	2	(1.45)	4	(14.81)
refused to answer	4	(2.90)	1	(3.70)
missing	5	(3.62)	0	(0)
Post-secondary education	176	(73.33)	19	(55.88)
don't know	6	(2.5)	2	(5.88)
missing	5	(2.08)	1	(2.94)
High income (>$70,000/year)	107	(44.58)	13	(38.24)
don't know	35	(14.58)	2	(5.88)
missing	39	(16.25)	6	(17.65)
Previous bicycling injury	75	(31.25)	9	(26.47)
n/a	140	(58.33)	22	(64.71)
missing	2	(0.83)	2	(5.88)
Injury details				
Head injury	25	(10.42)	4	(11.76)
n/a (lwbs*)	4	(1.67)	0	(0)
missing	1	(0.42)	0	(0)
Body region injured				
scalp/skull/head	37	(15.42)	6	(17.65)
spine	0	(0)	1	(2.94)
trunk	11	(4.58)	2	(5.88)

	Controls n=240	(%)	Cases n=34	(%)
upper extremity	120	(50)	14	(41.18)
lower extremity	54	(22.5)	11	(32.35)
multiple locations	13	(5.42)	0	(0)
no injury identified (lwbs*)	4	(1.67)	0	(0)
missing	1	(0.42)	0	(0)
Type of injury				
fracture	72	(30)	25	(73.53)
superficial	67	(27.92)	2	(5.88)
head injury	20	(8.33)	4	(11.76)
dislocation/sprain/strain	22	(9.17)	0	(0)
open wound/laceration	52	(21.67)	3	(8.82)
internal organ injury	1	(0.42)	0	(0)
dental injury	1	(0.42)	0	(0)
no injury identified (lwbs*)	4	(1.67)	0	(0)
missing	1	(0.42)	0	(0)

*Left without being seen

4.8.3 Characteristics of Excluded Bicyclists

In order to evaluate the potential for selection bias we examined the bicyclist and crash characteristics of bicyclists who were eligible, but not included in the study because they could not provide enough details about the crash location. The proportion of bicyclists excluded for this reason was small; there were 29 (12.4%) controls and 4 (5.4%) cases excluded.

Due to the very small number of excluded cases (4), we can only summarize their characteristics; any detailed description could result in a confidentiality breach if those bicyclists were identified. Two were motor-vehicle cases, and 2 were severe cases. Three bicyclists were bicycling to visit friends/family when their crash occurred, and 1 was bicycling for recreation. Two were between 13-17 years, 2 were older than 18, and 2 were male. One bicyclist suffered a fracture, and the other 3 had superficial injuries. None of the excluded cases suffered a head injury.

We compared the crash and bicyclist characteristics of excluded controls with those of the motor-vehicle and severe controls included in the study. Selected characteristics of the excluded controls are presented in table 4.23. Compared with the study sample, a higher proportion of excluded controls were bicycling to visit friends or family (17.2% vs. 6%), and were bicycling during mid-day (8:31-16:00) (55.17% vs. 32.64%). The most notable difference between the study sample and the excluded controls was that only 55.2% of excluded bicyclists were wearing a helmet, whereas 71% of study sample controls did so. Furthermore, compared with study controls, excluded controls suffered a higher proportion of head injuries (17.2% vs. 7.2% for motor-vehicle controls and 10.4% for severe controls). There was also a higher proportion of bicyclists in the 13-17 year age range among excluded bicyclists (27.6%) compared with the study sample (17% m-v controls, 18% severe controls).

Table 4.23 Characteristics of Excluded Controls

	Controls n=29	(%)
Male	21	(72.41)
Age <13 years	7	(24.14)
13-17 years	8	(27.59)
>18 years	14	(48.28)
Alcohol	3	(10.34)
n/a	12	(41.38)
High income	12	(41.38)
don't know	4	(13.79)
missing	4	(13.79)
Time of day		
06:31-08:30	0	(0)
08:31-16:00	16	(55.17)
16:01-18:00	4	(13.79)
18:01-24:00	6	(20.69)
00:01-06:30	2	(6.90)
missing	1	(3.45)
Reason bicycling		
going to/from work	1	(3.45)
visiting friends/family	5	(17.24)
going to/from party	0	(0)
fun/recreation	22	(75.86)
going to/from shopping	1	(3.45)
going to/from sports	0	(0)
going to/from school	0	(0)
Previously cycled at location	26	(89.66)
missing	1	(3.45)
Riding with others	18	(62.07)
Helmet	16	(55.17)
Injury details		
Head injury	5	(17.24)
Body region injured		(0)
scalp/skull/head	5	(17.24)
spine	0	(0)
trunk	1	(3.45)
upper extremity	17	(58.62)
lower extremity	6	(20.69)
Type of injury		
fracture	5	(17.24)
superficial	11	(37.93)
head injury	5	(17.24)

	Controls n=29	(%)
dislocation/sprain/strain	4	(13.79)
open wound/laceration	4	(13.79)

4.9 Injury Mechanisms

For cases, we examined injury mechanism by age groups to identify whether certain ages were more prone to a specific crash type. For motor-vehicle cases, older bicyclists (≥18 years) tended to be injured in motorist-at-fault events. A greater proportion of younger bicyclists were injured in bicyclist at fault, mid-block ride out, and other types of events. Most severe injuries were the result of bicyclist error. However, an important proportion of injuries in the 13-17 year age group were attributed to driver error.

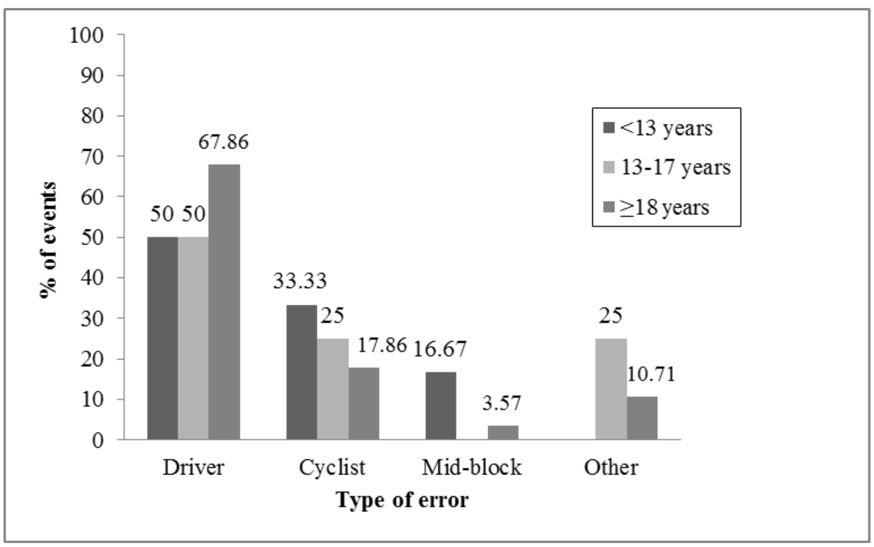


Figure 4.3 Type of Error by Age Group: Motor-Vehicle Cases

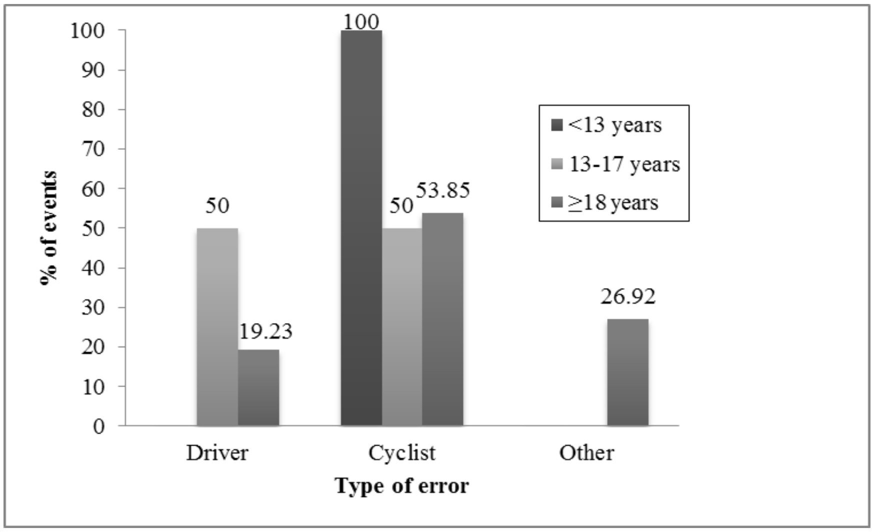


Figure 4.4 Type of Error by Age Group: Severe Cases

4.10 Matched Case-Control

There were 61 sets included in the matched analysis. There were 32 motor-vehicle case-control sets and 29 severe case-control sets. Cases without any time and day matched controls were not included in the matched analysis nor were non-time matched controls. Fourteen complete sets were excluded because they did not have any time matched controls, and 36 additional non-time matched controls were excluded.

Given the large number of potential risk factors collected during the audits and bicyclist interviews, Mantel-Haenszel summary estimates of the odds ratio (stratified on matched set) were calculated by hand for a selection of variables based on their previous indication as risk factors for motor-vehicle collision.(**56, 68**) These estimates were compared with those obtained from STATA using stratified analysis by matched set and by conditional logistic regression. Crude odds ratio estimates from conditional logistic regression were calculated for each environmental characteristic with corresponding 95% confidence intervals. For the adjusted analysis, the number of covariates added to the models was based on the number of discordant sets for each environmental characteristic (risk factor present in case and not present in controls or risk factor absent from case and present in at least one control), since the concordant sets do not contribute information to the odds ratio estimates. If there were missing values for a particular covariate (or a given predictor) it could affect the number of discordant sets. This was recognized, and the number of discordant sets was calculated in light of missing covariate observations.

Using the variable “services” an example is provided; among motor-vehicle sets, there were 17 discordant sets for “services”. Relaxing the 10% guideline, one covariate could be added to the crude model. There were no missing values for age or sex, so individually, these variables were added to the model providing age and sex adjusted estimates. There were 8 missing values for the covariate “faster than usual” and 14 for “cyclist high speed”. If any of these missing values were part of the original 17 discordant sets it could change a set making it concordant, or, if the case was missing for the covariate, the set no longer contributed to the estimate. For example, given a 2:1 matched set where one control is discordant (the other concordant), if the covariate “cyclist high speed” is missing for the discordant control, the set becomes concordant. There are now only 16 discordant sets for the variable “services”, which reduces the number of covariates the model can accommodate (i.e., the model cannot be adjusted for the covariate “cyclist high speed”). The effect of missing values on set discordance was examined for each environmental characteristic and each potential confounder.

4.10.1 Motor-Vehicle Case-Control Sets

Tables 4.24 and 4.25 provide the Mantel-Haenszel summary estimates of the odds ratio for the relationship between motor-vehicle collision and high speed limit (>30 km/hr), and collision and the presence of traffic control devices, without additional covariates (crude).

A small number of sets contributed to the crude estimate for high speed limit. The odds of being involved in a collision with a motor-vehicle were 3.8 times higher for those bicycling at locations with a speed limit >30 km/hr, compared with lower speed locations. This result was not statistically significant and the 95% confidence interval was wide because of the small number of contributing observations.

Table 4.24 Motor-Vehicle Matched Control Sets and High Speed Limit Discordance

		Number of controls at high speed locations				Mantel-Haenszel summary odds ratio inputs	
Case:control ratio	High speed cases					Numerator	Denominator
		0	1				
1:1	-	0	1			0	0.5
	+	0	7				
		0	1	2			
1:2	-	0	0	0		1.33	0
	+	1	2	7			
		0	1	2	3		
1:3	-	0	1	0	0	1.5	0.25
	+	0	1	4	4		
						Mantel-Haenszel summary odds ratio: (1.33+1.5)/(0.5+0.25)=3.77	**95% CI: 0.58-24.45**

A greater number of sets contribute information to calculating the estimate for the effect of traffic control devices. The crude estimate shows that the odds of motor-vehicle collision at locations with traffic controls are 2.7 (95% CI 1.16-7.05) times the odds for non-controlled locations. This estimate indicating a significant risk for bicyclists at traffic controlled locations is not all that surprising given the difference in the observed proportion of traffic controlled locations between cases and controls (57.14% vs. 31.28%).

Table 4.25 Motor-Vehicle Matched Control Sets and Traffic Control Discordance

		Number of controls with traffic controls	Mantel-Haenszel summary odds ratio inputs	
Case:control ratio	Traffic control cases		Numerator	Denominator
		0 1		
1:1	-	1 4	1.5	2
	+	3 1		
		0 1 2		
1:2	-	3 0 0	2.34	0
	+	3 1 2		
		0 1 2 3		
1:3	-	3 4 0 0	4.25	1
	+	5 1 0 0		
			Mantel-Haenszel summary odds ratio: (1.5+2.34+4.25)/(2+1)=2.7 95% CI: 1.16-7.05	

Table 4.26 summarizes the estimates for the effect of individual environmental characteristics on the outcome of motor-vehicle collision. The crude estimates are based on conditional logistic regression with the outcome variable and a single predictor in the model. For the adjusted estimates, the number of covariates included in the models is based on the 10% "rule of thumb" (**106**), and varies for each predictor because it is based on the number of discordant sets. In some instances the 10% rule has been relaxed in order to more persuasively address the issue of confounding. It has been suggested that relaxing the rule is appropriate in some situations, and that problems such as lower confidence interval coverage, higher type I error rate, or relative bias are "uncommon" with a less conservative rule of 5-9 events per variable.(**122**) For items with few discordant sets it was not possible

to conduct adjusted analyses. For variables with at least 17 discordant sets, one covariate was added to the crude model (e.g., age, sex, faster than typical, or bicyclist speed).

Traffic volume was a significant predictor of motor-vehicle events. Compared with low traffic volume sites, locations with medium volume had 4.66 (95% CI 1.4-15.51) times the odds of collision. The crude estimate for high volume was 2.85 (95% CI 1.05-7.67); however, the addition of age reduced the estimate by 41.05%, to 1.68 (95% CI 0.58-4.91). There was an indication that speed limit was related to motor-vehicle events; the crude odds ratio for locations where the speed limit was above 30 km/hr was 3.18 (95% CI 0.62-16.41) compared with lower speed locations. Although this result was not statistically significant, the size of the estimate cannot be ignored. This represents a 3-fold increase in the odds of being hit by a vehicle in areas where many people bicycle, for example, in residential areas where the speed limit is 50 km/hr.

For land use items, the highest odds of injury were where offices, retail, or services were present. The estimates for these features ranged from 3.89 (95% CI 1.29-11.69) for services to 8.8 (95% CI 0.99-78.16) for offices. Schools and natural features appeared to reduce the odds of motor-vehicle collision by approximately 50% each, although the confidence limits for the estimates contained the null value. Regardless, this represents a reduction in the odds of injury where vehicles drive slower (i.e., school/playground zones) and where there is likely to be less traffic (i.e., near parks, green spaces).

For path characteristics, there was an indication that primary paths located >3m from the road reduced the odds of collision, but the result was not statistically significant. Compared with paths adjacent to the road, those located >3m away had an age adjusted estimate of 0.17 (95% CI 0.02-1.53). This represents a greater than 80% reduction in the odds of collision, which is logical given that greater distance from the road reduces the possibility of encountering a vehicle. Inclined paths on side 1 appeared to increase the odds of collision, but the result was not statistically significant (OR 1.60, 95% CI 0.35-7.36). Interestingly, the result was in the opposite direction for inclined paths on side 2 (OR 0.15, 95% CI 0-1.99); however, only 5 sets contributed to this analysis and therefore this estimate should be regarded with caution. On side 2, the absence of a path indicated reduced odds of collision; the sex adjusted estimate was 0.32 (95% CI 0.10-1.01), but it should be noted that despite producing a 17% change, the sex adjusted estimate was only 0.07 lower than the crude. Path obstructions were positively related to the odds of injury on side 2; the odds were 3.83 (95% CI 1.03-14.25) compared with non-obstructed paths.

For characteristics of the roadway, slope, traffic control devices, and parking restriction signs signaled increased odds of injury; the estimates ranged from 1.52 (95% CI 0.33-6.93) for slope to 2.23 (95% CI 0.82-6.05) for parking restrictions. Despite not reaching statistical significance the estimates represent at least a 50% increase in the odds of collision. Curb design appeared to increase the odds of motor-vehicle collision. Compared with mountable curbs, non-mountable (i.e., square) curbs had adjusted estimates ranging from 1.88 (95% CI 0.58-6.06) after adjustment for age to 3.69 (95% CI 0.93-14.53) after adjustment for bicyclist speed. The age adjusted estimate for curb cuts (where the path slopes down to meet the road) was 1.85 (95% CI 0.53-6.47). At intersections, the age adjusted odds of collision with a vehicle were 6.89 (95% CI 1.48-32.14) compared with non-intersection sites.

The only aesthetic characteristic that was significantly related to collision was natural views (speed adjusted OR 0.2, 95% CI 0.05-0.72). A few safety and aesthetic characteristics had important OR estimates, although the confidence intervals encompassed the null value. These estimates ranged from 1.88 (95% CI 0.74-4.78) for destinations to 3.25 (95% CI 0.37-28.46) for >1 tree per block on side 1.

Table 4.26 Estimates of the Effect of Environmental Characteristics on Odds of Collision with a Motor-Vehicle: Matched Sets

				Adjusted for:							
		Crude	**95% CI**	**Age**	**95% CI**	**Sex**	**95% CI**	**Faster than usual**	**95% CI**	**Cyclist speed**	**95% CI**
Traffic and cyclist volume											
No bikes		0.82	(0.28-2.39)	0.95	(0.31-2.89)	0.88	(0.3-2.63)	€		€	
Traffic volume	low (≤250 vehicles/hr)	1	(reference)								
	med (250-749 vehicles/hr)	****4.66**	(1.4-15.52)	****4.88**	(1.32-18.11)	****4.46**	(1.33-14.94)	****5.13**	(1.44-18.27)	****4.90**	(1.28-18.73)
	high (≥750 vehicles/hr)	****2.85**	(1.06-7.67)	1.68	(0.58-4.91)	****2.92**	(1.07-7.96)	2.34	(0.75-7.24)	1.72	(0.56-5.25)
High avg. traffic speed (>30 km/hr)		1.37	(0.42-4.48)	*		*		*		*	
High speed limit (>30 km/hr)		3.18	(0.62-16.41)	*		*		*		*	
Land use											
Transport		0.79	(0.19-3.32)	*		*		*		*	
Housing		0.55	(0.18-1.66)	*		*		*		*	
Offices		8.8	(0.99-78.16)	*		*		*		*	
Retail		****7.71**	(2.48-23.94)	****5.56**	(1.72-17.98)	****7.56**	(2.43-23.5)	€		€	
Industry		2.07	(0.28-15.43)	*		*		*		*	
School		0.49	(0.13-1.89)	*		*		*		*	
Services		****4.91**	(1.68-14.36)	****3.8**	(1.29-11.69)	****5.45**	(1.8-16.46)	€		€	
Nature		0.47	(0.2-1.11)	0.53	(0.21-1.32)	0.47	(0.2-1.12)	0.51	(0.2-1.3)	0.38	(0.14-1)
Same predominant features side 1 & 2		0.53	(0.21-1.35)	0.55	(0.2-1.52)	0.50	(0.19-1.31)	0.54	(0.2-1.5)	€	
Path characteristics (side 1)											
Type of path	footpath	1	(reference)								
	no path	0.41	(0.04-3.87)	1.66	(0.14-19.75)	0.46	(0.05-4.33)	€		0.60	(0.06-6.04)
	multi-use path#	0.56	(0.15-2.13)	0.63	(0.16-2.51)	0.60	(0.16-2.29)	€		0.39	(0.07-2.11)

				Adjusted for:							
		Crude	**95% CI**	**Age**	**95% CI**	**Sex**	**95% CI**	**Faster than usual**	**95% CI**	**Cyclist speed**	**95% CI**
Path location	within 1m of road	1	(reference)								
	btw 1-3m of road	0.95	(0.25-3.53)	0.96	(0.26-3.62)	1.02	(0.26-3.95)	€		€	
	>3m from road	0.23	(0.03-1.88)	0.17	(0.02-1.53)	0.24	(0.03-1.94)	€		€	
Sloped		1.60	(0.35-7.36)	*		*		*		*	
Good path condition		0.49	(0.18-1.34)	0.78	(0.26-2.34)	0.50	(0.18-1.42)	€		€	
Path obstructions		1.21	(0.48-3.1)	1.05	(0.38-2.93)	1.16	(0.45-3)	1.23	(0.45-3.34)	€	
Path width <1.5m		0.5	(0.13-1.96)	*		*		*		*	
Path characteristics (side 2)											
Type of path	footpath	1	(reference)								
	no path	0.39	(0.13-1.13)	0.36	(0.11-1.2)	0.32	(0.1-1.02)	0.38	(0.12-1.26)	0.39	(0.13-1.24)
	multi-use path[#]	0.81	(0.18-3.69)	0.84	(0.18-3.97)	0.93	(0.21-4.24)	0.61	(0.1-3.78)	0.78	(0.12-4.95)
Path location	within 1m of road	1	(reference)								
	btw 1-3m of road	0.48	(0.09-2.49)			*		*		*	
Sloped		0.15	(0-1.99)	*		*		*		*	
Good path condition		0.67	(0.21-2.22)	*		*		*		*	
Path obstructions		**3.83	(1.03-14.25)	*		*		*		*	
Roadway characteristics											
Designated bike lane		0.64	(0.1-4.19)	*		*		*		*	
Sloped		1.52	(0.33-6.92)	*		*		*		*	
Good road condition		0.55	(0.2-1.52)	*		*		*		*	
> 4 lanes of traffic		2.35	(0.97-5.71)	1.52	(0.58-3.95)	2.39	(0.97-5.89)	2.62	(0.95-7.24)	1.64	(0.64-4.21)
Parking restrictions		**3.42	(1.35-8.67)	2.23	(0.82-6.05)	**3.34	(1.31-8.55)	**3.88	(1.31-11.55)	**3.84	(1.26-11.7)
Curb (side 1)	mountable	1	(reference)								
	non-mountable	**2.91	(1-8.46)	1.88	(0.58-6.06)	**3.03	(1.04-8.82)	2.64	(0.8-8.72)	3.69	(0.93-14.5)

	Crude	95% CI	Adjusted for: Age	95% CI	Sex	95% CI	Faster than usual	95% CI	Cyclist speed	95% CI
no curb	0.8	(0.12-5.18)	1.16	(0.16-8.52)	0.84	(0.13-5.59)	0.45	(0.04-4.59)	1.09	(0.17-7.06)
Curb cuts	2.71	(0.84-8.72)	1.85	(0.53-6.47)	2.71	(0.83-8.83)	€		€	
Traffic control devices	****3.06**	(1.25-7.51)	1.93	(0.72-5.14)	****3.20**	(1.28-8.05)	****2.74**	(1.02-7.35)	1.92	(0.73-5.1)
Intersection	****9.46**	(2.12-42.21)	****6.89**	(1.48-32.14)	****9.36**	(2.09-41.94)	€		€	
Crossings	2.5	(0.98-6.37)	1.68	(0.62-4.54)	2.58	(0.99-6.68)	2.63	(0.94-7.35)	1.87	(0.68-5.15)
Crossing	0.4	(0.1-1.52)	*		*		*		*	
Other	0.73	(0.33-1.6)	0.86	(0.38-1.93)	0.78	(0.34-1.79)	0.88	(0.37-2.09)	0.74	(0.3-1.83)
Safety characteristics										
Street lights (side 1)	0.99	(0.31-3.18)	*		*		*		*	
Street lights (side 2)	2.38	(0.51-10.99)	*		*		*		*	
Lighting over path (side 1)	0.7	(0.19-2.52)	*		*		*		*	
Lighting over path (side 2)	1.03	(0.3-3.53)	*		*		*		*	
Destination	2.36	(0.98-5.69)	1.88	(0.74-4.78)	****2.4**	(1.01-6)	2.28	(0.87-5.97)	2.44	(0.9-6.64)
Driveways	0.92	(0.38-2.18)	1.01	(0.41-2.47)	0.89	(0.37-2.13)	1.24	(0.47-3.23)	1.09	(0.43-2.76)
High surveillance	0.54	(0.22-1.29)	0.84	(0.32-2.19)	0.56	(0.23-1.36)	0.43	(0.16-1.17)	0.36	(0.12-1.11)
Aesthetic characteristics										
High garden maintenance	1.05	(0.42-2.65)	1.22	(0.42-3.57)	1.10	(0.43-2.8)	0.97	(0.33-2.86)	€	
High verge maintenance	0.76	(0.12-4.61)	*		*		*		*	
>1 tree/block (side 1)	3.25	(0.37-28.46)	*		*		*		*	
>1 tree/block (side 2)	0.99	(0.21-4.67)	*		*		*		*	
Tall trees (side 1)	2.27	(0.26-20.06)	*		*		*		*	
Tall trees (side 2)	1.53	(0.15-15.43)	*		*		*		*	
Clean	0.79	(0.33-1.86)	0.98	(0.39-2.44)	0.76	(0.32-1.8)	0.68	(0.25-1.85)	0.82	(0.3-2.2)
Natural	****0.32**	(0.12-0.86)	****0.2**	(0.07-0.69)	****0.3**	(0.12-0.88)	****0.34**	(0.12-0.99)	****0.20**	(0.05-0.72)
Similar buildings	0.62	(0.23-1.7)	0.94	(0.33-2.69)	0.54	(0.19-1.53)	€		€	
Attractive for walking	1.23	(0.3-5.03)	*		*		*		*	

			Adjusted for:							
	Crude	**95% CI**	**Age**	**95% CI**	**Sex**	**95% CI**	**Faster than usual**	**95% CI**	**Cyclist speed**	**95% CI**
Attractive for bicycling	0.66	(0.24-1.84)	*		*		*		*	
Difficult for bicycling	2.37	(0.83-6.74)	2.00	(0.68-5.92)	2.23	(0.77-6.44)	€		€	
Continuity of path	0.85	(0.18-4.11)	*		*		*		*	
Legible	0.68	(0.28-1.65)	0.54	(0.21-1.41)	0.73	(0.29-1.85)	0.60	(0.23-1.61)	€	

€ Estimate could not be adjusted because of missing data for the covariate
* Variables for which adjusted estimate cells are blank did not have enough discordant sets for models to accommodate additional covariates
# Multi-use path is a combination of marked and un-marked shared paths
** **Bold** estimates were significant at the 5% level

4.10.2 Severe Case-Control Sets

Table 4.27 provides a crude estimate for the odds of severe injury where the predominant path is a sidewalk compared with shared paths, or where no path is present (i.e., bicyclists ride on the road); the unadjusted odds of severe injury were 2.48 (95% CI 0.95-6.44) for locations where the predominant path was a sidewalk.

Table 4.27 Severe Matched Control Sets and Side 1 Sidewalk Discordance

		Number of controls with a sidewalk on side 1					Mantel-Haenszel summary odds ratio inputs	
Case-control ratio	Side 1 sidewalk cases						Numerator	Denominator
		0	1					
1:1	-	1	1				2	0.5
	+	4	0					
		0	1	2				
1:2	-	0	0	1			1.33	0. 67
	+	1	2	2				
		0	1	2	3			
1:3	-	2	1	3	0		3.5	1.75
	+	2	3	2	2			
		0	1	2	3	4		
1:4	-	0	0	0	0	0	0.4	0
	+	0	0	1	0	0		
		Mantel-Haenszel summary odds Ratio (2+1.33+3.5+0.4)/(0.5+0.67+1.75) = 2.48						**95% CI: 0.95-6.44**

Table 4.28 indicates the estimates for the effect of individual environmental characteristics on the outcome of severe injury. As with the motor-vehicle sets, the crude estimates are based on conditional logistic regression with the outcome variable and a single predictor. The adjusted estimates are presented for variables with a sufficient number of discordant sets to add a covariate. The greatest number of discordant sets for a single variable was 23, and as such, only one covariate was added to the models (one of

age, sex, faster than typical, or bicyclist speed) where the number of discordant sets permitted.

Greater traffic volume and higher speed indicated slightly increased odds of severe injury. Although the results were not statistically significant, the adjusted estimates for medium and high volume ranged from 2.89 (95% CI 0.68-12.36) to 3.20 (95% CI 0.63-16.25). These represent approximately a 3-fold increase in the odds of severe injury compared with low traffic volume locations. For vehicle speed, locations with speed limits above 30 km/hr had 1.85 (95% CI 0.46-7.47) times the odds, and estimated vehicle speed >30 km/hr had 1.7 (95% CI 0-3.91) times the odds. As was seen for motor-vehicle collisions, the odds of severe injury were high where retail establishments were present (OR 8.12, 95% CI 1.66-39.67), and low where there were schools (OR 0.24, 95% CI 0.03-1.05) and natural features (age adjusted OR 0.41, 95% CI 0.14-1.24).

Compared with sites with a sidewalk, locations with a multi-use path (marked or un-marked) appeared to have lower odds of severe injury. The odds ratio estimates for both sides ranged from 0.26 (95% CI 0.08-0.83) to 0.40 (95% CI 0.1-1.68) for side 2. Paths >3m away from the road also appeared to reduce the odds of severe injury; the adjusted estimates were 0.48 (95% CI 0.16-1.45) for side 1 and 0.36 (95% CI 0.06-2.06) for side 2. Although the estimate for path obstructions on side 2 was not significant the estimate of the odds ratio was 3.32 (95% CI 0.65-16.9).

When the road was in good condition, the odds of severe injury were lower (OR 0.25, 95% CI 0.07-0.96). Locations with >4 lanes of traffic and non-mountable curbs indicated greater risk of severe injury. The estimates ranged from 2.59 (95% CI 0.8-8.4) for many lanes to 3.52 (95% CI 0.91-13.62) for non-mountable curbs. None of the safety or aesthetic characteristics were found to be significant predictors of severe injury; however, a few items including >1 tree per block, cleanliness, and path continuity had relatively high estimates ranging from 1.85 (95% CI 0.64-5.31) to 3.0 (95% CI 0.35-25.96).

Table 4.28 Estimates of the Effect of Environmental Characteristics on the Odds of Severe Injury: Matched Sets

				Adjusted for:							
		Crude	95% CI	Age	95% CI	Sex	95% CI	Faster than typical	95% CI	Cyclist speed	95% CI
Traffic and cyclist volume											
No bikes		0.48	(0.16-1.45)	0.69	(0.23-2.12)	0.52	(0.17-1.59)	0.49	(0.16-1.49)	€	
Traffic volume	low (≤250 vehicles/hr)	1	(reference)								
	med (250-749 vehicles/hr)	1.98	(0.45-8.78)	1.53	(0.32-7.35)	2.93	(0.59-14.45)	3.20	(0.63-16.25)	€	
	high (≥750 vehicles/hr)	1.84	(0.48-7.06)	1.53	(0.39-6.07)	2.89	(0.68-12.36)	2.01	(0.51-7.94)	€	
High avg. vehicle speed (>30 km/hr)		1.7	(0-3.91)	*		*		*		*	
High speed limit		1.85	(0.46-7.47)	*		*		*		*	
Land use											
Transport		0.83	(0.16-4.23)	*		*		*		*	
Housing		1.16	(0.46-2.95)	1.35	(0.51-3.59)	1.10	(0.43-2.81)	1.21	(0.48-3.04)	€	
Retail		[**]**8.12**	(1.66-39.7)	*		*		*		*	
School		0.24	(0.03-1.05)	*		*		*		*	
Services		0.7	(0.21-2.31)	*		*		*		*	
Nature		0.63	(0.25-1.58)	0.41	(0.14-1.24)	0.60	(0.23-1.53)	0.54	(0.2-1.43)	0.74	(0.25-2.19)
Same predominant features side 1 & 2		0.77	(0.29-2.04)	0.73	(0.27-1.97)	0.83	(0.31-2.21)	0.81	(0.3-2.16)	€	
Path characteristics (side 1)											
Type of path	footpath	1	(reference)								
	no path	1.43	(0.27-7.52)	1.57	(0.27-9.06)	1.56	(0.28-8.56)	1.29	(0.24-6.81)	€	
	multi-use path [#]	[**]**0.26**	(0.08-0.83)	[**]**0.25**	(0.07-0.86)	[**]**0.29**	(0.09-0.95)	[**]**0.24**	(0.08-0.77)	€	
Path location	within 1m of road	1	(reference)								

				Adjusted for:							
		Crude	95% CI	Age	95% CI	Sex	95% CI	Faster than typical	95% CI	Cyclist speed	95% CI
	btw 1-3m of road	0.76	(0.22-2.64)	0.54	(0.14-2.09)	0.86	(0.24-3.07)	0.86	(0.23-3.15)	€	
	>3m from road	0.6	(0.21-1.73)	0.48	(0.16-1.45)	0.70	(0.24-2.06)	0.60	(0.2-1.76)	€	
Path material	concrete/bricks	0.7	(0.06-7.91)	*		*		*		*	
Sloped path		0.42	(0-1.63)	*		*		*		*	
Good path condition		0.65	(0.22-1.95)	*		*		*		*	
Path obstructions		0.38	(0.13-1.06)	0.36	(0.13-1.01)	0.38	(0.13-1.01)	0.37	(0.12-1.03)	€	
Path width <1.5m		0.8	(0.23-2.72)	*		*		*		*	
Path characteristics (side 2)											
Type of path	footpath	1	(reference)								
	no path	0.95	(0.32-2.86)	1.14	(0.36-3.62)	0.89	(0.29-2.69)	0.96	(0.32-2.92)	€	
	multi-use path[#]	0.48	(0.12-1.93)	0.40	(0.1-1.68)	0.46	(0.11-1.9)	0.43	(0.08-2.19)	€	
Path location	within 1m of road	1	(reference)								
	btw 1-3m of road	0.4	(0.08-2.13)	0.11	(0.01-1.64)	0.42	(0.07-2.44)	0.56	(0.1-3.33)	€	
	>3m from road	0.65	(0.16-2.64)	0.36	(0.06-2.06)	0.68	(0.14-3.24)	1.01	(0.14-7.47)	€	
Sloped path		1.11	(0.23-5.32)	*		*		*		*	
Good path condition		0.52	(0.09-3.12)	*		*		*		*	
Path obstructions		3.32	(0.65-16.9)	*		*		*		*	
Roadway characteristics											
Designated bike lane		1.41	(0.08-23.57)	*		*		*		*	
Sloped road		0.68	(0.17-2.69)	*		*		*		*	
Good road condition		[**] **0.25**	(0.07-0.96)	*		*		*		*	
> 4 lanes of traffic		2.59	(0.8-8.4)	*		*		*		*	
Parking restrictions		1.11	(0.37-3.33)	*		*		*		*	
Curb (side 1)	mountable	1	(reference)								

				Adjusted for:							
		Crude	95% CI	Age	95% CI	Sex	95% CI	Faster than typical	95% CI	Cyclist speed	95% CI
	non-mountable	** **4.27**	(1.11-16.37)	3.52	(0.91-13.62)	** **4.51**	(1.08-18.8)	** **4.08**	(1.06-15.64)	€	
	no curb	0.45	(0.05-4.36)	0.42	(0.04-3.92)	0.34	(0.04-3.17)	0.34	(0.03-3.71)	€	
Curb cuts		1.24	(0.51-3.02)	1.12	(0.45-2.82)	1.28	(0.52-3.14)	1.28	(0.51-3.19)	1.29	(0.48-3.28)
Traffic control devices		0.51	(0.15-1.79)	*		*		*		*	
Intersection	Path-road	1	(reference)								
	Path-path	0.63	(0.16-2.5)								
	Any vs. none	0.66	(0.26-1.71)	0.57	(0.2-1.64)	0.63	(0.24-1.65)	0.61	(0.23-1.64)	€	
Crossings		1.1	(0.39-3.15)	*		*		*		*	
Crossing aids		1.14	(0.28-4.57)	*		*		*		*	
Other routes		0.53	(0.22-1.31)	0.58	(0.22-1.53)	0.49	(0.19-1.25)	0.44	(0.16-1.16)	0.59	(0.22-1.57)
Safety characteristics											
Street lights (side 1)		1.45	(0.59-3.54)	1.90	(0.7-5.12)	1.40	(0.58-3.53)	1.49	(0.61-3.64)	1.18	(0.42-3.3)
Street lights (side 2)		0.89	(0.29-2.77)	*		*		*		*	
Lighting over path (side 1)		0.36	(0.07-1.86)	*		*		*		*	
Lighting over path (side 2)		0.58	(0.16-2.15)	*		*		*		*	
Destinations		0.95	(0.39-2.32)	1.03	(0.4-2.69)	0.97	(0.39-2.39)	0.93	(0.38-2.28)	1.22	(0.42-3.5)
Driveways		0.71	(0.28-1.81)	1.15	(0.41-3.21)	0.69	(0.27-1.77)	0.70	(0.27-1.8)	€	
High surveillance		0.53	(0.17-1.71)								
Aesthetic characteristics											
High garden maintenance		0.55	(0.21-1.46)	0.64	(0.21-1.89)	0.57	(0.21-1.53)	0.54	(0.21-1.43)	€	
>1 tree/block (side 1)		2.19	(0.41-11.78)	*		*		*		*	
>1 tree/block (side 2)		1.98	(0.22-17.88)	*		*		*		*	
Tall trees (side 2)		0.41	(0.06-2.93)	*		*		*		*	
Clean		1.85	(0.64-5.31)	1.79	(0.59-5.43)	1.85	(0.63-5.38)	1.81	(0.63-5.18)	€	

			Adjusted for:							
	Crude	**95% CI**	**Age**	**95% CI**	**Sex**	**95% CI**	**Faster than typical**	**95% CI**	**Cyclist speed**	**95% CI**
Natural views	0.68	(0.25-1.84)	0.54	(0.18-1.57)	0.72	(0.27-1.98)	0.64	(0.23-1.78)	€	
Similar buildings	0.55	(0.18-1.72)	*		*		*		*	
Attractive for bicycling	0.4	(0.13-1.23)	*		*		*		*	
Difficult for walking	2.04	(0.48-8.66)	*		*		*		*	
Difficult for bicycling	1.48	(0.56-3.96)	1.27	(0.45-3.54)	1.30	(0.47-3.58)	1.39	(0.52-3.73)	€	
Continuity of path	3	(0.35-25.96)	*		*		*		*	
Legible	1.21	(0.44-3.33)	0.90	(0.29-2.87)	1.37	(0.48-3.91)	1.24	(0.45-3.43)	€	

[€] Estimate could not be adjusted because of missing data for the covariate

[*] Variables for which adjusted estimate cells are blank did not have enough discordant sets for models to accommodate additional covariates

[#] Multi-use path is a combination of marked and un-marked shared paths

[**] **Bold** estimates were significant at the 5% level

4.11 Un-Matched Case-Control

The un-matched analysis included 274 sites. There were 42 motor-vehicle cases (195 controls) and 34 severe cases (240 controls). Tables 4.29 and 4.30 present the results of the unconditional multiple logistic regression for motor-vehicle and severe case-control groups respectively.

4.11.1 Motor-Vehicle Cases and Controls

Traffic volume was significantly related to motor-vehicle collisions. Compared with low volume, medium and high volume locations had age adjusted estimates of 3.49 (95% CI 1.37-8.88) and 2.83 (95% CI 1.24-6.42), respectively. Speed limit >30 km/hr had an estimate of 2.59 (95% CI 0.87-7.71). While the confidence interval contained the null value (1.0), this represents a greater than 2-fold increase in the odds of collision where vehicles travel faster; a finding which should not be disregarded for lack of statistical significance.

The point estimates for offices, retail, and services indicated an increase in risk. The adjusted estimates ranged from 2.02 (95% CI 0.96-4.23) for services to 7.54 (95% CI 3.15-18.03) for retail. Natural land use (e.g., green spaces, parks, ponds) was found to reduce the odds of collision (OR 0.44, 95% CI 0.21-0.91).

The only path characteristic that had a significant association with motor-vehicle events was the presence of obstructions on side 2. Adjusted for bicyclist speed, the estimated OR was 2.59 (95% CI 1.13-5.9). The further away from the road a path was located the lower the odds of an event. Compared with paths adjacent to the road, the adjusted estimates for paths 1-3 meters and >3 meters away ranged from 0.16 (95% CI

0.02-1.29) to 0.62 (95% CI 0.24-1.64). No other path characteristics showed an indication of a relationship with collisions.

Locations where there were >4 lanes of traffic or parking restrictions appeared to increase the odds of motor-vehicle events. The estimated effects were lower after adjusting for age and peak time (adjusted OR [aOR] 1.40; 95% CI 0.65-3.03 and aOR 1.74; 95% CI 0.85-3.55, respectively). After adjustment, one roadway characteristic showed a significant association with collisions; the adjusted estimate for intersection was 2.83 (95% CI 1.11-7.2).

The presence of destinations was the most important predictor among the safety features examined. The adjusted estimate was 2.35 (95% CI 1.11-4.97). The crude estimate for streetlights on side 2 showed an indication of a positive effect on the odds of an event, but the association did not remain when adjusted for age (aOR 1.54, 95% CI 0.43-5.58). The only aesthetic characteristic that had a significant relationship with motor-vehicle events was natural surroundings, with an estimate of 0.43 (95% CI 0.21-0.8)

Table 4.29 Environmental Risk Factors for Motor-Vehicle Collision

		Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
Traffic and cyclist volume						
No bikes		0.71	(0.32-1.59)	1.08	(0.46-2.55)	age & cyclist high speed
Traffic volume	low (≤250 vehicles/hr)	1.00	reference			
	med (250-749 vehicles/hr)	****3.66**	(1.46-9.16)	****3.49**	(1.37-8.88)	age
	high (≥750 vehicles/hr)	****3.92**	(1.8-8.55)	****2.83**	(1.24-6.42)	age
High avg. traffic speed (>30 km/hr)		1.98	(0.78-5.04)	1.50	(0.54-4.13)	weekday peak, age & cyclist high speed
High speed limit (>30 km/hr)		2.59	(0.87-7.71)	Ω		
Land use						
Transport		1.51	(0.52-4.38)	1.12	(0.35-3.52)	age, cyclist high speed & riding fast
Housing		0.51	(0.23-1.13)	0.59	(0.23-1.53)	age, weekday peak, & riding fast
Offices		****9.55**	(2.65-34.36)	3.01	(0.73-12.36)	age, weekday peak, & riding fast
Retail		****7.15**	(3.37-15.14)	****7.54**	(3.15-18.03)	age & cyclist high speed
Industry		3.20	(0.52-19.78)	3.70	(0.48-28.82)	age & cyclist high speed
School		0.65	(0.22-1.98)	0.68	(0.18-2.6)	age & cyclist high speed
Services		****2.54**	(1.24-5.21)	2.02	(0.96-4.23)	age
Nature		****0.44**	(0.21-0.91)	Ω		
Same predominant features side 1 & 2		0.76	(0.39-1.48)	Ω		
Path characteristics (side 1)						
Type of path	footpath	1.00	reference			
	no path	1.20	(0.42-3.47)	1.30	(0.43-3.89)	cyclist high speed
	shared without markings	0.42	(0.05-3.34)	0.45	(0.05-3.71)	cyclist high speed
	shared with markings	0.98	(0.37-2.57)	1.35	(0.48-3.79)	cyclist high speed
	no path	1.20	(0.42-3.47)	1.30	(0.43-3.89)	cyclist high speed

		Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
	multi-use path #	0.82	(0.33-2.01)	1.05	(0.41-2.68)	cyclist high speed
Path location	within 1m of road	1.00	reference			
	btw 1-3m of road	0.69	(0.26-1.8)	0.40	(0.14-1.12)	age & weekday peak
	>3m from road	0.14	(0.02-1.04)	0.16	(0.02-1.29)	age & weekday peak
Sloped path		0.85	(0.27-2.63)	1.14	(0.35-3.71)	riding fast
Good path		0.69	(0.34-1.41)	0.71	(0.32-1.59)	age & cyclist high speed
Path obstructions (any)		1.80	(0.88-3.7)	Ω		
Path width <1.5m		0.74	(0.35-1.56)	0.94	(0.43-2.07)	age
Path characteristics (side 2)						
Type of path	footpath	1.00	reference			
	no path	0.55	(0.23-1.28)	0.54	(0.22-1.33)	cyclist high speed & weekday peak
	shared without markings	1.06	(0.11-9.86)	0.85	(0.09-8.37)	cyclist high speed & weekday peak
	shared with markings	1.59	(0.57-4.45)	2.16	(0.65-7.12)	cyclist high speed & weekday peak
	no path	0.55	(0.23-1.28)	0.68	(0.28-1.68)	cyclist high speed & age
	multi-use path #	1.48	(0.57-3.87)	1.69	(0.59-4.85)	cyclist high speed & age
Path location	within 1m of road	1.00	reference			
	btw 1-3m of road	0.80	(0.33-1.96)	0.62	(0.24-1.64)	cyclist high speed
Sloped path		0.80	(0.22-2.97)	0.72	(0.18-2.98)	weekday peak, riding fast & cyclist
Good path condition		0.86	(0.39-1.87)	0.96	(0.39-2.35)	age & cyclist high speed
Path obstructions (any)		**2.16**	(1.01-4.65)	**2.59**	(1.13-5.9)	cyclist high speed
Roadway characteristics						
Designated bike lane (any)		2.49	(0.71-8.69)	1.83	(0.42-8.02)	weekday peak, riding fast & age
Sloped road		0.71	(0.23-2.16)	1.01	(0.32-3.23)	riding fast
Good road condition		0.70	(0.35-1.39)	0.93	(0.45-1.89)	age
> 4 lanes of traffic		**2.52**	(1.28-4.97)	1.40	(0.65-3.03)	age & weekday peak

		Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
Parking restrictions		****2.25**	(1.13-4.46)	1.74	(0.85-3.55)	age
Curb (side 1)	mountable	1.00	reference			
	non-mountable	1.59	(0.79-3.2)	1.35	(0.65-2.82)	riding fast
	no curb	0.55	(0.12-2.53)	0.55	(0.12-2.56)	riding fast
Curb cuts		1.33	(0.66-2.69)	0.82	(0.38-1.78)	riding fast & age
Traffic control devices (any)		****2.84**	(1.44-5.62)	1.59	(0.74-3.45)	age & weekday peak
Intersection		****3.61**	(1.45-9)	****2.83**	(1.11-7.2)	age
Crossings		****2.33**	(1.17-4.66)	1.54	(0.73-3.26)	age & weekday peak
Crossing aids		0.69	(0.29-1.67)	0.43	(0.16-1.18)	age & cyclist high speed
Other routes		0.56	(0.28-1.11)	Ω		
Safety characteristics						
Street lights (side 1)		1.28	(0.55-2.97)	1.06	(0.45-2.53)	weekday peak
Street lights (side 2)		2.31	(0.67-7.98)	1.54	(0.43-5.58)	age
Lighting over path (side 1)		1.56	(0.56-4.38)	1.95	(0.68-5.6)	age
Lighting over path (side 2)		1.70	(0.69-4.16)	Ω		
Destinations		****2.80**	(1.35-5.79)	****2.35**	(1.11-4.97)	riding fast
Driveways		1.10	(0.54-2.22)	1.34	(0.63-2.86)	cyclist high speed
High surveillance		0.73	(0.37-1.42)	Ω		
Aesthetic characteristics						
High garden maintenance		0.93	(0.46-1.87)	Ω		
High verge maintenance		0.57	(0.22-1.47)	0.85	(0.31-2.33)	cyclist high speed
>1 tree/block (side 1)		1.42	(0.54-3.74)	1.71	(0.63-4.63)	riding fast
>1 tree/block (side 2)		1.07	(0.4-2.87)	0.76	(0.24-2.37)	riding fast & weekday peak & cyclist
Tall trees (side 1)		0.91	(0.19-4.45)	1.08	(0.21-5.45)	riding fast
Tall trees (side 2)		1.01	(0.21-4.8)	0.77	(0.14-4.31)	riding fast & weekday peak & age
Clean		0.64	(0.31-1.31)	Ω		

	Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
Natural views	**0.43** [**]	(0.21-0.86)	Ω		
Similar buildings	0.51	(0.26-1)	0.90	(0.41-1.95)	riding fast & age & weekday peak
Attractive for walking	0.60	(0.24-1.53)	0.83	(0.32-2.15)	age
Attractive for bicycling	0.49	(0.22-1.12)	0.58	(0.25-1.34)	age
Difficult for walking	1.18	(0.37-3.72)	1.92	(0.55-6.66)	cyclist high speed & weekday peak
Difficult for bicycling	1.53	(0.75-3.14)	1.25	(0.59-2.61)	age
Continuity of path	**1.13** [**]	(1.31-4.11)	0.59	(0.14-2.43)	riding fast & age
Legible	0.99	(0.48-2.04)	0.69	(0.32-1.47)	cyclist high speed

[Ω] None of the covariates changed the crude estimate by >15% therefore the crude was retained

[#] Multi-use path is a combination of marked and un-marked shared paths

[**] **Bold** estimates were significant at the 5% level

4.11.2 Severely Injured Cases and Controls

Traffic volume was not a significant predictor of severe injury. Compared with low volume, the adjusted estimated odds ratios for medium and high volume were 1.22 (95% CI 0.37-4.01) and 1.53 (95% CI 0.61-3.85), respectively. These results do not provide evidence that traffic volume is related to severe injury, although it was related to motor-vehicle collisions. There was an indication that high average vehicle speed was related to severe injuries, the adjusted odds ratio was 4.13 (95% CI 0.89-19.11).

The presence of retail establishments significantly increased the odds of severe injury (aOR 2.53, 95% CI 1.1-5.83). There was an indication that schools reduced the odds of severe injury; however, the result was not significant (aOR 0.35, 95% CI 0.04-2.84).

Concrete primary paths indicated reduced odds of severe injury (aOR 0.41, 95% CI 0.03-4.73). Two path characteristics on the secondary side appeared to increase the odds of severe injury; multi-use paths (aOR 2.12, 95% CI 0.73-6.21) or sloped paths (OR 1.93, 95% CI 0.65-5.75), but the results were not statistically significant. Path width also appeared to have some (not significant) effect. Where the path was <1.5m, the odds of severe injury were 0.43 (95% CI 0.18-1.05).

For roadway characteristics, locations with >4 lanes of traffic increased the odds of severe injury by 2.31 (95% CI 0.87-6.16) compared with fewer lanes. The estimate for good road condition showed reduced odds of injury (OR 0.43, 95% CI 0.19-0.96). This estimate represents a greater than 50% reduction in the odds of severe injury when the road was well maintained.

While not all the adjusted estimates were statistically significant, our results showed that lighting reduced the odds of severe injury; the estimates ranged from 0.38-0.93. At the lower end for the range, this represents a greater than 60% reduction where lighting is present. The adjusted estimate for locations with good surveillance from surrounding buildings was 0.32 (95% CI 0.13-0.82).

For aesthetic characteristics, high verge maintenance was associated with reduced odds of severe injury (OR 0.31, 95% CI 0.1-0.99) and the estimate for path continuity was in the direction of increased odds (aOR 2.34, 95% CI 0.29-19.04). Attractiveness for bicycling had an adjusted estimate of 0.49 (95% CI 0.18-1.32) and locations rated as difficult for walking or bicycling appeared to have increased odds of injury, with estimates ranging up to 2.14 (95% CI 0.65-7.07).

Table 4.30 Environmental Risk Factors for Severe Injury

		Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
Traffic and cyclist volume						
No bikes		0.64	(0.27-1.54)	0.89	(0.33-2.36)	cyclist high speed & age
Traffic volume	low (≤250 vehicles/hr)	1.00	reference			
	med (250-749 vehicles/hr)	1.29	(0.4-4.19)	1.22	(0.37-4.01)	age
	high (≥750 vehicles/hr)	2.00	(0.84-4.79)	1.53	(0.61-3.85)	age
High avg. vehicle speed (>30 km/hr)		1.76	(0.58-5.41)	4.13	(0.89-19.11)	cyclist high speed & riding fast
High speed limit		1.14	(0.41-3.21)	Ω		
Land use						
Transport		1.47	(0.47-4.58)	0.95	(0.25-3.54)	age & cyclist high speed
Housing		0.65	(0.3-1.42)	Ω		
Offices		0.70	(0.09-5.62)	0.49	(0.06-3.99)	age
Retail		**3.11	(1.38-6.98)	**2.53	(1.1-5.83)	age
Industry		4.94	(0.79-30.68)	1.84	(0.18-18.98)	age & cyclist high speed
School		0.44	(0.1-1.92)	0.35	(0.04-2.84)	age & cyclist high speed
Services		1.17	(0.5-2.74)	0.54	(0.19-1.54)	age & cyclist high speed
Nature		1.25	(0.6-2.57)	Ω		
Same predominant features		0.89	(0.42-1.86)	1.15	(0.51-2.62)	cyclist high speed
Path characteristics (side 1)						
Type of path	footpath	1.00	reference			
	no path	1.10	(0.3-4.02)	1.00	(0.27-3.65)	riding fast
	shared without	1.78	(0.65-4.84)	1.61	(0.59-4.42)	riding fast
	shared with markings	0.99	(0.35-2.8)	0.74	(0.24-2.3)	riding fast
	no path	1.10	(0.3-4.02)	Ω		

		Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
	multi-use path #	1.30	(0.59-2.87)	Ω		
Path location	within 1m of road	1.00	reference			
	btw 1-3m of road	1.70	(0.65-4.46)	1.68	(0.59-4.81)	cyclist high speed
	>3m from road	1.19	(0.48-2.93)	1.42	(0.52-3.85)	cyclist high speed
Path material	concrete/bricks	1.00	(0.12-8.37)	0.41	(0.03-4.73)	age & cyclist high speed
Sloped path		1.53	(0.61-3.83)	1.83	(0.71-4.76)	cyclist high speed
Good path condition		0.58	(0.27-1.24)	0.71	(0.32-1.57)	age
Path obstructions (any)		0.81	(0.38-1.74)	Ω		
Path width <1.5m		0.43	(0.18-1.05)	Ω		
Path characteristics (side 2)						
Type of path	footpath	1.00	reference			
	no path	0.94	(0.36-2.44)	0.93	(0.36-2.42)	weekday peak
	shared with markings	1.52	(0.46-5.03)	2.87	(0.82-10.07)	weekday peak
	shared without	2.81	(0.81-9.81)	1.47	(0.44-4.91)	weekday peak
	no path	0.94	(0.36-2.44)	0.86	(0.28-2.65)	age & cyclist high speed
	multi-use path #	1.98	(0.77-5.07)	2.12	(0.73-6.21)	age & cyclist high speed
Path location	within 1m of road	1.00	reference			
	btw 1-3m of road	0.86	(0.26-2.85)	0.96	(0.28-3.31)	cyclist high speed
	>3m from road	1.45	(0.5-4.19)	1.95	(0.59-6.49)	cyclist high speed
Sloped path		1.93	(0.65-5.75)	Ω		
Good path condition		0.88	(0.36-2.19)	1.16	(0.45-3.01)	age
Path obstructions (any)		1.10	(0.45-2.73)	Ω		
Roadway characteristics						
Designated bike lane (any)		0.71	(0.09-5.76)	0.71	(0.08-6.03)	age & riding faster than usual
Sloped road		1.28	(0.41-4.01)	0.95	(0.23-3.85)	age, cyclist high speed & riding fast

		Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
Good road condition		**0.43	(0.19-0.96)	Ω		
> 4 lanes of traffic		**2.43**	(1.08-5.47)	2.31	(0.87-6.16)	age, cyclist high speed & riding fast
Parking restrictions		0.89	(0.37-2.14)	0.66	(0.26-1.64)	age
Curb	mountable	1.00	reference			
	non-mountable	1.62	(0.71-3.71)	Ω		
	no curb	0.44	(0.05-3.53)	Ω		
Curb cuts		1.27	(0.61-2.63)	Ω		
Traffic control devices (any)		1.18	(0.51-2.76)	0.88	(0.36-2.14)	age
Intersection	any vs. none	0.96	(0.45-2.05)	Ω		
	Path-road	1.00	reference			
	Path-path	1.25	(0.43-3.66)	0.70	(0.18-2.64)	cyclist high speed
Crossings		1.58	(0.7-3.58)	1.85	(0.75-4.58)	cyclist high speed
Crossing aids		1.12	(0.42-2.95)	Ω		
Other routes		0.92	(0.44-1.91)	0.75	(0.34-1.68)	cyclist high speed
Safety characteristics						
Street lights (side 1)		0.93	(0.43-2.01)	0.78	(0.34-1.79)	cyclist high speed
Street lights (side 2)		0.67	(0.3-1.49)	****0.38**	(0.15-0.97)	age & cyclist high speed
Lighting over path (side 1)		0.55	(0.21-1.45)	0.43	(0.15-1.22)	sex
Lighting over path (side 2)		0.48	(0.19-1.21)	0.39	(0.15-1.04)	sex
Destinations		1.06	(0.52-2.18)	0.80	(0.36-1.77)	cyclist high speed
Driveways		0.62	(0.3-1.27)	Ω		
High surveillance		0.48	(0.21-1.07)	****0.32**	(0.13-0.82)	cyclist high speed
Aesthetic characteristics						
High garden maintenance		0.53	(0.25-1.11)	Ω		
High verge maintenance*		****0.31**	(0.1-0.99)	Ω		
>1 tree/block (side 1)		1.35	(0.48-3.83)	2.07	(0.57-7.53)	cyclist high speed

	Crude OR	95% CI	Adjusted OR	95% CI	Adjustment factors
>1 tree/block (side 2)	1.49	(0.48-4.61)	1.75	(0.48-6.42)	cyclist high speed
Tall trees (side 2)	0.77	(0.16-3.67)	Ω		
Clean	1.52	(0.6-3.85)	Ω		
Natural views	1.47	(0.7-3.12)	Ω		
Similar buildings	0.67	(0.3-1.49)	0.84	(0.37-1.92)	age
Attractive for walking	0.83	(0.27-2.57)	1.08	(0.34-3.39)	age
Attractive for bicycling	0.59	(0.24-1.48)	0.49	(0.18-1.32)	age & cyclist high speed
Difficult for walking	1.47	(0.47-4.58)	2.14	(0.65-7.07)	cyclist high speed
Difficult for bicycling	1.44	(0.67-3.07)	1.19	(0.5-2.84)	age, cyclist high speed & riding fast
Continuity of path	3.46	(0.45-26.52)	2.34	(0.29-19.04)	age, cyclist high speed & riding fast
Legible	1.26	(0.56-2.83)	1.46	(0.56-3.79)	cyclist high speed

Ω None of the covariates changed the crude estimate by >15% therefore the crude was retained

Multi-use path is a combination of marked and un-marked shared paths

** **Bold** estimates were significant at the 5% level

4.12 Sensitivity Analysis – Propensity and Summary Risk Score

For the sensitivity analysis using propensity scores and summary risk score, we chose to examine one specific exposure, the presence of designated bicycle lanes. There were a few reasons for choosing this exposure. First, the estimate for the relationship between bike lanes and motor-vehicle collisions in the un-matched analysis was important (OR 2.49, 95% CI 0.71-8.69, aOR 1.83, 95% CI 0.42-8.02), yet it was not statistically significant. With an indication that bike lanes may present a near 2-fold increase in risk, a closer look at this variable was warranted. Also, current evidence on the effect of bike lanes on the roadway is mixed. While some studies have shown that they result in lower odds of injury,(**24**) others have found that when cyclists share facilities with motorists, regardless of whether there is a marked or painted separation, the odds of injury or fatality are higher.(**24**) We wanted to gain more perspective into how bike lanes influence bicycling safety.

4.12.1 Simultaneous Adjustment for Confounders and Conventional Logistic Regression Results Comparison

The propensity score and summary risk score models both included 8 variables (including 2 levels for traffic volume). The distribution of the scores was checked to ensure balance between exposed and non-exposed bicyclists; figures 4.5 and 4.6 plot these results.

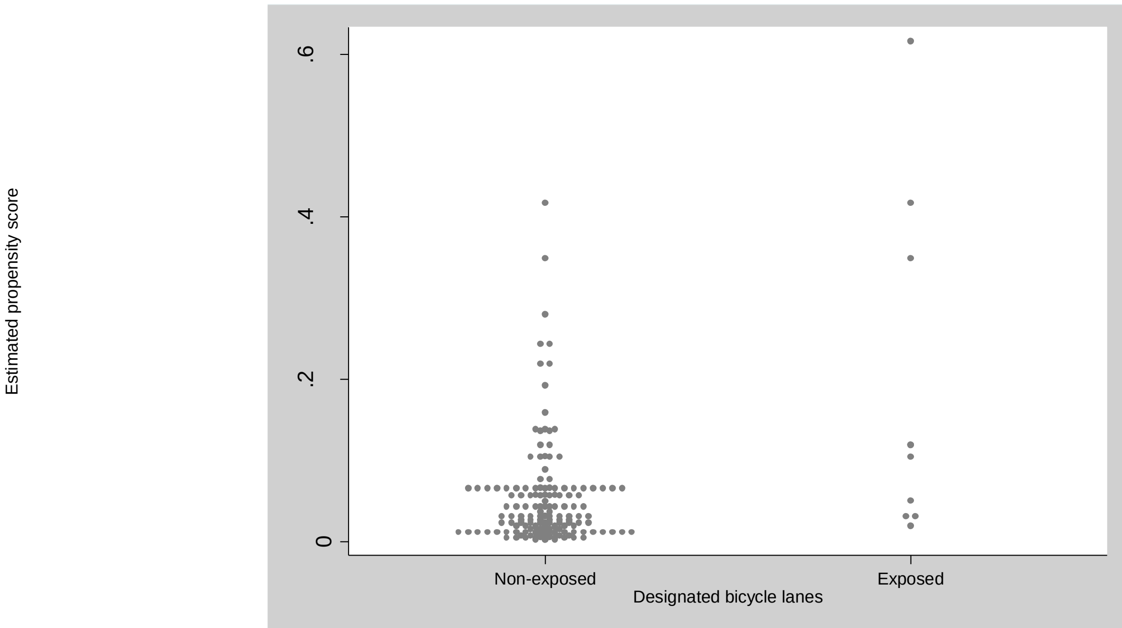


Figure 4.5 Propensity Dot Pot by Exposure Status for Designated Bicycle Lanes

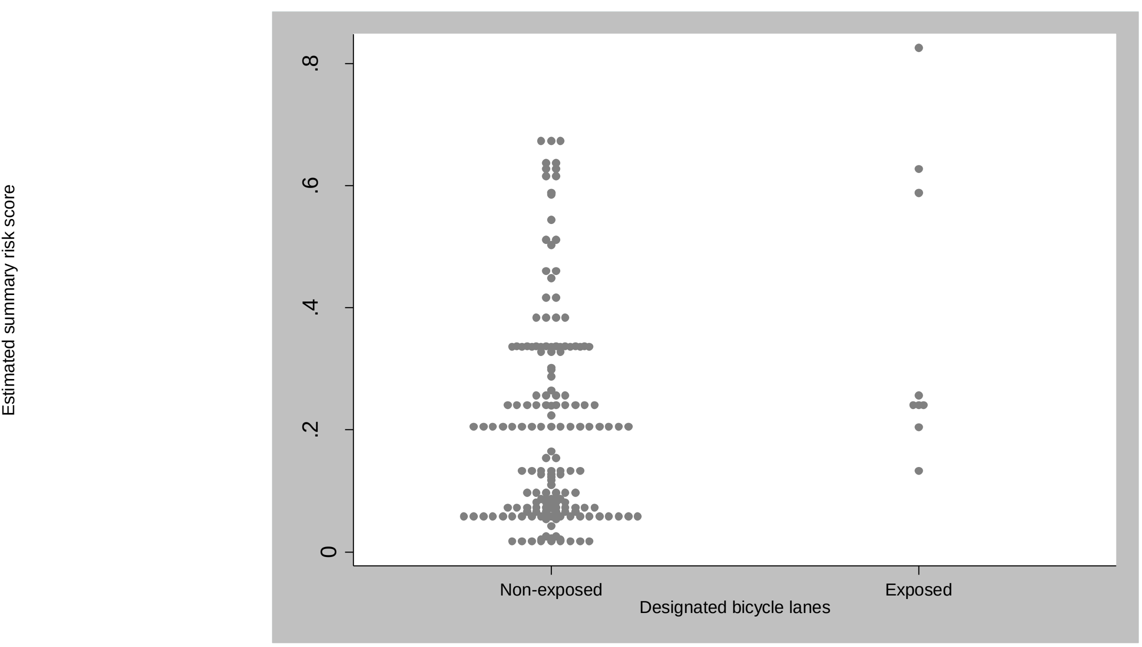


Figure 4.6 SRS Dot Pot by Exposure Status for Designated Bicycle Lanes

Table 4.31 compares the crude, adjusted, propensity score, and summary risk score modelled estimates. The size of the crude estimate (i.e., not adjusted for any confounders) indicated a possible relationship between motor-vehicle collisions and bicycle lanes. The adjusted results continued to show that an effect may be present, but not as strong as the crude estimate suggested. The estimate including the propensity score was lower than the estimate including the SRS. Both were slightly lower than the adjusted estimate from the multivariable regression, providing some indication that using the scores produced a more conservative estimate. The confidence limits for the propensity score and SRS estimates were narrower than the conventional adjusted estimate, indicating that using the scores increased the precision of the estimate to some degree.

Without knowing with certainty whether or not a relationship exists between motor-vehicle collisions and bicycle lanes, it is unclear exactly which estimate results in less bias; however, conclusions drawn from the propensity and SRS methods may temper conclusions that there is great risk associated with bicycle lanes.

Table 4.31 Multiple Logistic Regression, Propensity Score, and Summary Score Adjusted Estimates for Bike Lanes

	Multivariable logistic regression				**Propensity score**		**Summary risk score**	
	Crude OR	95% CI	aOR	95% CI	aOR	95% CI	aOR	95% CI
Designated bicycle lanes (any)	2.49	(0.71-8.69)	1.83*	(0.42-8.02)	1.64	(0.42-6.46)	1.77	(0.41-7.71)

*estimate was adjusted for peak time and riding fast

The simultaneous adjusted methods (i.e., propensity and SRS) were explored briefly to examine the potential for using these methods in the future. This type of approach may provide advantages with our data given the large number of potential confounders and the limited sample size, and further consideration of this strategy is warranted.

Chapter Five: Discussion

This study provided a foundation on which future studies on the relationship between the natural and built environment and bicyclist safety can build. Our results confirmed that traffic volume was a significant risk factor for bicycle-motor-vehicle collisions; medium and high volume locations presented a 3 to 4-fold increase in the odds of collision compared with low volume locations. At intersections, the odds of collision were nearly 3 times that of non-intersection locations. Path obstructions also presented an increased risk of motor-vehicle collisions. For severe injury risk factors, we found that good road condition reduced the odds by 60% (OR 0.43; 95% CI 0.19-0.96). There was an indication that multi-use paths also reduced the odds of severe injury by up to 70% (OR 0.26; 95% CI 0.08-0.83). When we examined the risk associated with various types of land use, we found that bicyclists were more at risk of being involved in a collision or seriously injured when bicycling in commercial areas, particularly near retail establishments. Some aesthetic and safety items, such as streetlights (aOR 0.38; 95% CI 0.15-0.97) and high surveillance (aOR 0.32; 95% CI 0.13-0.82) were protective for severe injuries. We have produced a comprehensive description of the locations where bicycling injuries occur, and more specifically, we have brought attention to features of the environment that increase the likelihood of being involved in a collision with a motor-vehicle, or suffering a severe injury. Table 5.1 summarizes the study findings regarding risk factors for motor-vehicle and severe injury events.

Table 5.1 Summary of Risk Factors for Motor-Vehicle and Severe Injury Events

Motor-vehicle collision risk factors	Estimated effect on odds of injury	Severe injury risk factors	Estimated effect on odds of injury
Greater traffic volume	↑	Good road condition	↓
Intersections	↑	Street lights	↓
Path obstructions	↑	High surveillance	↓
Retail land use	↑	Retail land use	↑
Non-mountable curbs	↑	Non-mountable curbs	↑
Destinations	↑	Verge maintenance	↓
Parking restrictions	↑	Multi-use path	↓
Traffic control devices	↑		
Natural features	↓		

5.1 Motor-Vehicle and Severe Injury Risk Factors

When comparing the factors related to motor-vehicle and severe injury outcomes we found that factors related to one outcome were not necessarily related to the other. Recognizing that features of the environment associated with motor-vehicle collisions and severe injuries in bicyclists may differ from one another is important for planners, as it signals that multiple design elements need to be considered in order to reduce the occurrence of each type of event. Of course, focusing on the factors that are identified as predictors of both outcomes is crucial.

5.1.1 Bicyclist and Traffic Volume

5.1.1.1 Bicyclist Volume

Bicycle volume did not appear to be related to the odds of motor-vehicle collision or severe injury. It is important to consider this finding in light of the fact that recreational and transportation related bicycle use are relatively low in Alberta compared with other areas.(**29**) The “safety in numbers” effect has been demonstrated in the Netherlands, a country with very high rates of bicycling.(**17**) It is unclear whether the association between higher numbers of bicyclists and fewer injuries can be attributed to bicyclist volume, or whether these areas were "safer" for bicycling a priori.(**74**) Our study included very few sites with high bicyclist volume, and several locations where no bicyclists were observed during a 30 minute observation period. It may be possible that a bicyclist volume threshold must be reached before the "safety in numbers" effect is demonstrated.

5.1.1.2 Traffic Volume

Traffic volume was a significant risk factor for motor-vehicle collisions; however, the effect was not as strong for severe injuries. This could be because motor-vehicle-bicycle encounters do not always result in severe injury. The fact the odds ratio estimates for severe injury were lower, and did not reach statistical significance may also be because of low power to detect a potentially greater effect, since severe injury sites included several non-roadway locations that did not contribute to the analysis for volume. For both outcomes, the estimated odds ratios indicated an increased risk where traffic volume and speed were higher. When volume estimates were adjusted for age, the size of the effect was reduced, especially for the effect of high volume. This may reflect the fact that younger bicyclists are less likely to ride at higher volume locations. When looking at the results within volume categories, the estimates for high traffic volume were lower than those for medium volume. This may be related to the type of road configuration at medium and high volume locations. For example, high volume roads might be thoroughfares where traffic flow is uninterrupted (e.g., highways), and where there are fewer opportunities for bicyclists and vehicles to cross paths. Alternatively, medium volume locations might be areas where there are many intersections, presenting more opportunities for bicyclist-vehicle encounters. In fact, intersections were significant predictors of bicyclist-motor-vehicle collisions, but had little effect on the outcome of severe injury. While few studies have directly examined the link between traffic volume and bicyclist injury, it has been shown that roads that are designed to accommodate more traffic, such as arterials and divided roads, increase the overall risk of bicyclist-vehicle events.(**71, 73**) Several studies on pedestrians have demonstrated that traffic volume has a large impact on their risk of injury.(**101, 102**) Given that bicyclists and motorist often share the road to a greater degree than pedestrians and motorists, it is reasonable to expect that the effect of volume on bicyclist injury would be more pronounced than the effect for pedestrians.

5.1.1.3 Vehicle Speed

The estimates for average vehicle speed and speed limit were in the positive direction for both outcomes (OR range 1.14-3.54). The confidence intervals for the estimates for motor-vehicle and severe outcomes overlapped, providing no evidence of a difference in these estimates. While there was not a significant association between speed limit and injury, the estimates ranged from 1.14-3.18. At the upper range, this represents a 3-fold increase in the odds of injury where speed limit exceeds 30 km/hr. Others have found that vehicle speed is one of the most important predictors of bicyclist injury.(**46, 56, 123**) Kim at al. reported that where speed exceeded 80 km/hr, the risk of death increased by 16 times compared with locations where speed was 32 km/hr.(**46**) Similarly, others found that bicyclist fatalities were more likely to occur in events where the vehicle driver was at fault and speeding (OR 8.27; 95% CI 5.78-11.82).(**56**) These estimates are much higher than what we found, but the results are not directly comparable given that the aforementioned studies focused on bicyclist fatalities, had much larger sample sizes, used different data sources, and were mostly concerned with determining the types of crashes (i.e., injury mechanism) that result in severe injury or death. Regardless, the indication of a relationship between vehicle speed and bicyclist injury provides a basis for injury prevention initiatives targeting speed reduction, particularly given that vehicle speed is a relatively easily modifiable factor.(**71**)

There is additional evidence that motorized transportation reduces the number of bicyclists and pedestrians.(**36, 85**) Traffic therefore, has a dual negative effect on bicyclists and pedestrians; not only is the incentive to bicycle or walk reduced by motor-vehicle traffic, but the risk of injury also increases. Consequently, it is important to consider facilities and designs that allow for vulnerable road users to be separated from traffic, while ensuring it is possible and even convenient for them to reach key destinations. Separating bicyclists and vehicles has the potential to increase the number of bicyclists as well as reduce the number of injuries caused by motor-vehicle events.

5.1.2 Roadway Characteristics

5.1.2.1 Curb Design

Several roadway characteristics were associated with motor-vehicle related injuries, and a few were shown to be linked with severe injury. Non-mountable (square) curbs appeared to be related to both outcomes (OR range 1.35-3.52). Square curbs are a challenge for bicyclists, who must either manoeuvre over them (hop), or get off their bicycle to get over the curb. Because getting off the bicycle is inconvenient and even fear-provoking when vehicles are present, bicyclists often crash while trying to “hop” the curb. Another scenario where square curbs may be dangerous is when bicyclists riding on the road are “squeezed” by vehicles. When the curb is mountable, bicyclists can ride up onto the sidewalk when vehicles travel too close. With a square curb, this is not possible and bicyclists may impact with the curb. In our study, approximately 50% of locations had mountable curbs; choosing this design more often may help reduce the number of curb impact crashes. To our knowledge, no other studies have examined the impact of curb design on bicyclist injury, or on the motivation to bicycle.

5.1.2.2 On-Road Bicycle Lanes

The estimates for bicycle lanes were in opposite directions for motor-vehicle and severe events. In addition, the direction differed for each outcome by analysis approach. In the un-matched analysis lanes appeared to increase the odds for motor-vehicle collisions, while the estimate for severe injuries indicated a reduction. The adjusted estimates for bicycle lanes were 0.71 (95% CI 0.08-6.03) for severe injury, and 1.83 (95% CI 0.42-8.02) for motor-vehicle events. In the matched analysis, the opposite result was seen; the estimate was positive for severe injury, and below 1 for motor-vehicle outcomes. However, the issue of power in the matched sample may have generated this result.

As our results demonstrated, there is mixed evidence about the effect of bicycle lanes on injury and crash rates. In their review, Reynolds et al. found 5 studies that indicated an approximate 50% reduction in injury rates, collision frequency, or crash rates where bicycle lanes were present (compared with roadways without bicycling infrastructure).(**24**) One study review found an increase in crash rates after the installation of marked bike lanes, but the effect diminished in the long term. Reynolds et al. highlighted that it is challenging to compare the results of studies in this area because various types of facilities are often grouped into categories, which differ from one study to the next.(**24**)

Hoffman et al. published a study after the release of the Reynolds et al. review, where they examined factors related to minor and severe injury (requiring medical attention) among commuter bicyclists. They found that both types of injuries occurred mostly on bike lanes/wide shoulders and on residential streets.(**27**) When compared with each other, minor injuries were more likely to occur on major roads without bicycle facilities, and severe events were more likely on residential streets and bicycle boulevards.(**27**) As mentioned by Reynolds et al., differences in the study designs and methodology might explain differences in the evidence to date. Hoffman et al. included only commuters (i.e., those bicycling to work) and the study was conducted in Portland, Oregon, a city known for its well-developed bicycle network and facilities. Bicyclists in the city are relatively more likely to have access to various types of bicycle infrastructure, so it is predictable that more events occurred at these locations.

A Calgary bicyclist-commuter survey conducted in 2006 found that bicyclists spent an average of 45% of their journey bicycling on the road, and that 44% rode on the sidewalk at some point during their trip (**124**) despite that this is not permitted and known to be more dangerous.(**24, 65, 66**) This signals a need for improved on-road bicycle facilities, or roadway adjacent bicycle paths. In fact, the improvement most requested by commuters was additional bike lanes both inside and outside the downtown core.(**124**) In a systematic review of the effect of built environment characteristics on bicycling, Fraser and Lock found parallel evidence, with several studies showing a positive association and statistically significant change in the number of bicycle commuters with a greater density of on street bike lanes.(**125**) Given the evidence we found that traffic volume and speed are predictors of injury, it would be preferable if facilities were off-road at high volume/speed locations, and if designated on-road lanes were created on lower-risk routes still providing bicyclists direct access to key destinations, such as shopping centres and schools.

5.1.2.3 Road Condition

Good road condition significantly reduced the odds of a severe injury only. The adjusted estimates from the matched analysis indicated a 75% reduction in the odds of severe injury where the road was in good condition. Small maintenance issues on the road such as loose gravel, cracks, or holes, especially on the shoulder, do not necessarily affect vehicles, but create additional risks for bicyclists. These concerns may be even more important during the winter and spring when road conditions tend to be worse and the shoulder is often covered in snow. Yan et al. found that poor road conditions were a significant factor in increasing bicyclist-motor-vehicle collisions in events where motorists turned without due care. They speculated that this could be because motorists are paying attention to abnormalities in the road instead of watching out for other road users.(**123**) These findings bring attention to the idea that factors beyond the facilities themselves can have an effect on bicyclists. Maintenance issues such as timely snow clearing in the winter and gravel removal in the spring can have an impact on the willingness to ride as well as the safety of bicyclists.

5.1.2.4 Other Roadways Factors

In the un-matched analysis several factors including traffic control devices, parking restrictions, and crossings had important crude estimates in the positive direction for motor-vehicle collisions (OR range 2.25-2.84). After adjusting for age the estimates ranged from 1.54-1.74. Because many severe injury sites were not roadways, it is possible that these features are in fact related to severe injury, but that our sample size (i.e., power) affected our ability to establish a relationship.

The evidence to date on traffic control devices and bicyclist injury is mixed, likely because many different types of traffic control designs exist and the effect of each type has not been thoroughly examined. In a Calgary study, Rifaat et al. found that traffic signals reduced the probability of a fatal injury to vulnerable road users (pedestrians and bicyclists).(**71**) However, the study focused on the risk of fatality given that a crash had already occurred, and does not provide an indication of the effect of traffic signals on the injury event itself. In addition, the study included pedestrians and bicyclists, and did not distinguish between the two.

Several studies have examined bicyclist injury risk at roundabouts, which have been shown to be associated with increased risk especially when they are designed with multiple traffic lanes or marked bike lanes.(**24, 68, 69**) We did not observe any locations with roundabouts, but did find that other traffic control devices appeared to increase the odds of a motor-vehicle collision. One downside of our examination of traffic control devices is that several designs (e.g., stop signs, lane narrowing) were grouped into a single category. This was necessary given the small number of locations that had any devices at all. As a result, we could not distinguish the effect of individual designs. Future research should focus on this, and on separately examining locations where traffic control devices were installed to replace signalized intersections (e.g., roundabouts), and where they were designed to modify traffic flow (e.g., chicanes, lane narrowing), as it is possible that different implementation purposes have different effects on injury outcomes.

The effect of parking restrictions has received little attention in the literature. One study evaluating bicyclist preferences for facilities found that after more on-road bicycle lanes, the most preferred improvement was to eliminate or reduce the presence of on-street parking.(**38**) In our study, the presence of signs prohibiting parking or indicating parking regulations had estimates ranging from 1.84-2.23 for motor-vehicle collisions. This hints that different parking arrangements may have an effect on bicyclist- motor-vehicle collisions. While we were not able to differentiate the effect of different types of parking regulations, we observed that a greater proportion of motor-vehicle case locations were parking lots. Parking lots are congested areas where drivers are focused on avoiding other vehicles and pedestrians, and are likely not expecting to encounter bicyclists. In comparison, a similar proportion of case and control locations were sites where parallel parking or angle parking were permitted. These parking arrangements also create opportunities for bicyclist-vehicle encounters, for example, when bicyclists are struck by motorists opening vehicle doors. One way to reduce the occurrence of these types of events is to make drivers aware, for example, through driver training programs, that it is necessary to look out for bicyclists in parking lots, as well as when opening vehicle doors when street side parking.

We found that where crossings were present there was nearly a 2-fold increase in the odds of being struck by a motor-vehicle or sustaining a severe injury (aOR range 1.10-1.85). While we did not differentiate between types of crossings, other research has suggested that different types of markings, colours, and designs have different influences on the risk of collision.(**24, 72**) The evidence for the effect of different crossings is mixed and further studies examining these, while controlling for potential confounders such as bicyclist volume, are needed. It should also be recognized that the effects of various crossing designs are likely to be very context/site specific.

5.1.3 Path Characteristics

5.1.3.1 Type of Path

In the matched analysis only, significantly lower odds of severe injury were observed for locations with shared marked or multi-use pathways compared with sidewalks. Bicycle paths are reported to be favoured by many bicyclists, and have been linked to increased bicycling.(**81**) Our result is similar to what we already know in regards to paths. Several studies, including two conducted in Canada, found an increased risk of injury associated with riding on sidewalks compared with off-road paths.(**24, 65, 66**) Another found a reduced risk of injury on bicycle paths compared with the road(**67**), and others have found reduced odds of fatality or hospitalization when bicycling on a facility other than the road (e.g., sidewalk, driveway, multi-use path). (**13, 40**) The growing amount of evidence reinforces the idea that facilities dedicated to bicycling should be implemented as much as possible to avoid bicyclists travelling on the road or the sidewalk.

5.1.3.2 Path Location

For both outcomes, paths further away from the road seemed to have lower odds of injury (aOR range 0.14-1.42). For motor-vehicle outcomes, this result is intuitive – the farther the bicyclist is from traffic, the less likely they are to be hit. Interestingly, path obstructions on the secondary side showed an association for both outcomes, with estimates representing up to a 3-fold (except for severe cases in the un-matched analysis) increase in the odds of injury where the path was obstructed. A possible explanation for this is that obstructed paths force bicyclists to travel on the road where they have increased exposure to traffic and can end up in a collision. Obstructions on the secondary side may also lead bicyclists to ride on the primary side where perhaps there are more pedestrians, creating opportunities for encounters between path users.

5.1.3.3 Other Path Features

Studies have found mixed evidence regarding the effect of path slope on the willingness to ride a bicycle. Some have found that hills are a significant deterrent for current and would-be bicyclists while others have found no indication that hills impact the decision to bicycle.(**81**) One study that modelled various road and path features that may be related to injury found that steeper grade increased injury severity.(**126**) These mixed results are likely due to the differences in the bicyclists sampled or the individual factors controlled for during analysis (e.g., experience). In our study, sloped paths were not significantly associated with injuries. Calgary and Edmonton have similar topography with a flat central core and some elevation near the river valleys. In both cities, the chance of encountering a sloped path is fairly high if bicyclists commute to work since most residential areas are located outside the core; however, our study included many recreational bicyclists, who may be more likely to ride within residential areas or along the rivers. There were 98 locations where either the path or road was reported to have a moderate or steep slope. While we did not control for bicyclist experience, our sample included a variety of different bicyclist abilities that may have led to our null result. Intuitively, path slope may increase risk when bicyclists travel downhill at high speed, or when they travel uphill and have difficulty manoeuvring and reduced sight lines.

The results for path characteristics further reinforce the need for paths that are separated from the road and free of obstacles; our findings also signal the need to consider having separate paths dedicated to pedestrians and wheeled activities.

5.1.4 Land Use

For land uses, there was some evidence that offices, retail, and services (OR range 2.54-8.80) were related to motor-vehicle crashes; only retail was related to severe injury. It is likely that these commercial sites have more traffic volume, density, intersections and distractions, creating many opportunities for encounters between bicyclists and vehicles, although they may not necessarily result in serious injury. The relationship between commercial establishments and bicyclist-vehicle crashes was documented in a study by Dumbaugh and Li, who reported that strip commercial uses and big box stores were associated with increases in the number of bicyclist-vehicle encounters.(**73**)

For both outcomes, after adjusting for various factors, the presence of schools and natural features reduced the risk. Drivers likely expect to encounter pedestrians and bicyclists, particularly children, at these types of locations and may be more attuned to look out for them. These types of land use are associated with lower vehicle speeds (e.g., school and playground zones), and in some cases, lower traffic volume. A recent study in Calgary found that mean vehicle speed in school and playground zones was significantly lower than the default speed on urban roads, and only slightly higher than the posted speed limit of 30 km/hr.(**127**) In addition, the study found that several other roadway features resulted in lower speeds including: speed display devices, fencing, and traffic controls devices.(**127**) Some of these, for example, speed displays, are relatively easy and affordable, and could be used at various types of locations beyond school zones to help reduce speeding.

In contrast to our findings, others have reported that children are more likely to be injured near schools, or the trip to/from school.(**128, 129**) However, possible confounding factors that were not examined in these studies could influence the relationship observed, in particular, bicyclist volume. Since our study was not limited to children, the difference in our results may also be due to differences in the study sample composition.

Given the large body of research focusing on neighbourhoods and how the area surrounding a person's home is related to physical activity or active transportation (**80, 83, 130**), it may have been expected that features of the environment thought to contribute to activity level may also be related to injury. Interestingly, residential locations were not significantly associated with either motor-vehicle events or severe injuries. Approximately half of the sites we visited were residential, indicating that many injuries occur in these areas, yet the type of land use itself does not appear to be a predictor of injury. This reinforces the importance of examining other specific features of the environment around one's home, which is what we set out to do in this study. It also highlights the need for researchers to examine the relationship between physical activity and the micro level features of the environment, in addition to the broader overall land uses.

5.1.5 Safety and Aesthetic Characteristics

Streetlights, surveillance, and verge maintenance were associated with significant reductions in the odds of severe injury (aOR range 0.31-0.38). While few studies have examined specific safety or aesthetic features and injuries together, some studies have examined the effect of street lighting. These studies have found that unlit areas present a greater risk of severe injury, and that lighting helps to reduce injuries in rural areas.(**46, 56, 131**) It is important to keep this evidence in mind, especially in areas such as Alberta where it is dark early in the morning and during the evening, when people commute during large periods of the year.

Large estimates were also found for >1 tree per block (OR range 1.35-3.25), tall trees (OR range 0.77-2.27), and difficulty for bicycling (OR range 1.25-2.00), indicating that these characteristics may increase the odds of injury. This is likely because trees and other obstacles reduce sight lines and visibility, and make it difficult for bicyclists to manoeuvre. Natural views and locations described as attractive for bicycling presented lower odds of injury. Similarly, a study of motivators and deterrents of current and would-be bicyclists found that the strongest motivator of the decision to bicycle was that the route was aesthetically pleasing.(**36**)

5.1.6 Injury Mechanisms

Injury mechanism information was collected for cases only. The results for the types of errors that led to injuries were similar to the findings by Rowe et al.(**44**) Our results indicated that younger bicyclists tended to be injured in bicyclist-at-fault events, while older bicyclists tended to be injured as a result of driver error. Still, an important proportion of both motor-vehicle and severe injury events involving children were attributed to driver error. To improve safety of bicyclists at the population level, separating bicyclists from traffic should be a priority; however, this type of initiative takes time and alternative approaches are necessary while infrastructure changes take place. For example, targeting motor-vehicle speed reduction, especially near school or playground zones might help. Another approach could be to incorporate more focus on vulnerable user groups as part of driver education/training and testing.

5.1.7 Bicyclist Characteristics

The focus of this study was to examine the characteristics of locations where bicycling injuries occurred. In gathering this information we also collected information on the injured bicyclists themselves, including demographics, helmet use, and injury details. There is a large body of evidence on individual risk factors for bicycling injuries, and while we did not specifically examine how individual characteristics were related to motor-vehicle or severe injury outcomes, we did include several known risk factors as potential confounders for the environmental features we examined. Furthermore, the descriptive statistics of the study sample provide some information about those who suffer bicycle injuries.

5.1.7.1 Age and Sex

For both case-control groups (motor-vehicle and severe), 70% or more of the injured bicyclist were male. This is consistent with other studies, which have reported a higher proportion of injured males compared with females (between 70-90% male).(**15, 39, 44, 47**) The fact that there are more injuries among males is likely a reflection that there are more male than female bicyclists; however, men have also been found to have higher odds of suffering a fatal injury when involved in a collision with a vehicle.(**56**) In our sample, a higher proportion of controls compared with cases were younger than 13 years old, and cases tended to be older than 18 years. Age has repeatedly been shown to be related to bicycling injury risk; several studies have found that older bicyclists have higher relative odds of collision, and are more likely to be seriously injured or killed.(**7, 40, 43, 45, 46**) Given this evidence, age and sex were included as potential confounders in our regression models.

5.1.7.2 Helmet Use

Helmet use was lower in cases than controls. Helmet use ranged from 42.86% for motor-vehicle cases, to 71.28% for motor-vehicle controls. In Calgary and Edmonton, helmet use is only mandatory for those less than 18 years old, and has been reported to be approximately 50% among those older than 18 years. For adolescents (13-17 years), helmet use has been reported to be over 60%, and over 90% for those younger than 13.(**54, 132**) There is strong evidence indicating that helmets reduce the risk of a head, brain, and severe brain injury, and there is additional evidence that after helmet legislation is implemented, helmet use increases and injury rates decline.(**51, 52**) The low proportion of helmet use among cases in our study reinforces the need to create awareness about the benefits of helmet use, and provides additional cues that signal the need for all-ages helmet legislation.

5.1.7.3 Trip Purpose

Nearly 50% of motor-vehicle cases were bicyclists commuting to work or school. While it is logical that this group has a greater likelihood of being involved in a collision due to higher exposure to traffic, greater distance/time travelled, and route choice, it is important to examine this group closely. Several studies have focused on individual characteristics of commuters and factors influencing route choice and decision to ride.(**27, 32, 33, 133**) However, few have examined how specific features of the natural and built environment along commuter routes may relate to injury. This group would be expected to benefit greatly from evidence generated from studies like ours. By liaising with local bicycle groups, we will be able to share the findings of our study with these key end users.

5.1.7.4 Injuries

In general, controls suffered more upper extremity injuries, while cases tended to injure the lower extremities. The type of crash is a likely explanation for this; cases injured in collisions with motor-vehicles are often struck on the lower body. Additionally, lower extremity injuries, such as fractures, tend to be more severe than upper extremity injuries and often require surgery or hospitalization. Our results for injured body regions mirror the injury profile of bicyclists described in other studies, where the primary regions injured among hospitalized bicyclists are the extremities, as well as the head/neck.(**39, 40**)

In the motor-vehicle outcome group, cases suffered a higher proportion of head injuries including concussions, minor head injuries, and intracranial injuries compared with controls. Other studies have documented that head injuries tend to be more severe, as measured, for example, by injury severity scores, and more likely to result in hospitalization or death compared with other types of injuries.(**7, 39, 40, 45**) In our study, the proportion of head injuries among severely injured cases was similar to the proportion among controls. However, we grouped various types and degrees of head injuries together. Had we divided the spectrum of head injuries into categories (e.g., concussion vs. intracranial injuries) we may have seen a higher proportion of severe head injuries among cases.

5.2 Limitations

As in any epidemiologic investigation, the possibility of confounding, selection bias, and misclassification bias must be recognized along with the implications of these limitations on the study findings.

5.2.1 Confounding Bias

Confounding can be described as a mixing of effects, where the effect of the exposure, in this case, individual environmental features, is mixed together with the effect of another variable which is an independent risk factor for the outcome in question.(**134**) In order for a variable to act as a confounder it cannot be in the causal pathway between the exposure and the outcome. The presence of confounding leads to bias, with a resulting over or under estimation of the effect under investigation.

We examined the effect of several potential confounders previously shown to be related to bicycling injuries: age, sex, self-reported bicyclist speed, bicycling faster than usual, and time of day.(**7, 13, 64**) In both the matched and un-matched investigations, age appeared to have the greatest impact on the odds ratio estimates, especially for motor-vehicle events. The risk of injury or death from bicycling has been shown to vary with age.(**7, 45, 56**) Our estimates indicated the same effect. For example, locations with >4 lanes of traffic were associated with increased odds of motor-vehicle collision when no other variables were considered. When age was added to the model, the estimated effect was reduced and no longer statistically significant. Age is known to be an independent risk factor for motor-vehicle collisions, and it is possible that age is related to lanes of traffic in that younger bicyclists may be less likely to ride where there are many lanes. Further, age is not on the pathway between >4 lanes and motor-vehicle events. As such, age is identified as a confounder in the relationship between lanes and motor-vehicle events. In this case, ignoring the effect of age would have resulted in an overestimation of the effect of traffic lanes on motor-vehicle events.

Bicyclist speed (both self-reported speed and bicycling faster than usual) also appeared to have an influence on some of the estimates. An example is when we examined the relationship between path location, motor-vehicle collisions, and the potential confounding effect of self-reported bicyclist speed. Path location would logically be expected to be related to motor-vehicle collisions (i.e., the farther the bicyclist is from the road, the less likely they are to be hit). It also follows that path location would be related to bicyclist speed; when bicyclists are located closer or farther from the road, they may choose to ride more quickly, or to slow down. While there is a lack of evidence as to whether bicyclist speed is directly related to motor-vehicle events, there is strong evidence that it is associated with severe injury.(**7**) When the simple effect of location was estimated (i.e., crude estimate), paths further away from the road had lower odds of collision. When bicyclist speed was added, the estimate for location was reduced, indicating that ignoring the effect of speed under-estimated the effect of path location on motor-vehicle events. Rivara et al. reported that speed was independently associated with motor-vehicle events (**45**), where those who bicycled faster than 15 mph had 1.2 times the odds of suffering severe injury. In our study in general bicyclist speed tended to increase the risk. Given the distribution of self-reported speed in our sample, high speed was set at ≥15 km/hr. At this cut-off, self-reported speed has been reported to be valid when compared with objectively measured bicyclist speed.(**109**)

Time (peak vs. non-peak) was also found to be a confounder, particularly in the motor-vehicle injury group. The estimates for several path characteristics including path type and location were adjusted for peak time. When peak time was the only covariate included in the models for the environmental characteristics, the size of the estimates were reduced. The limited evidence available on the relationship between time and bicyclist injury indicates that those travelling during peak time are at higher risk of suffering a fatal injury.(**46**) We did not find that peak time affected the odds of severe injury (only motor-vehicle collision). The discrepancy between the effects of peak time observed in our study and the study by Kim et al. may be due to their focus on the independent effect of time on injury severity. In addition, it is unclear whether or not they controlled for possible confounders, including age and sex.

We attempted to collect information on as many potential confounders as possible, but it is possible that some factors we did not have information on could be independently related to the outcomes and the environmental characteristics we examined. One possible confounder we were not able to examine was bicyclist volume. While we did count bicyclists, the vast majority of the sites we visited were classified as low/no bicyclist volume. Given the lack of information on this item it was not included in the adjusted analysis. Bicyclist volume has been reported to be associated with a reduction in the number of bicyclist injuries (i.e., the "safety in numbers" effect), but a causal relationship has not been established.(**16, 17, 74**) We did examine bicyclist volume as an independent predictor of motor-vehicle events and severe injuries and did not find evidence of an association. Still, it is possible that bicyclist volume may be associated with some of the environmental features we examined, in particular, path and aesthetic characteristics.

Where paths are concerned, when more bicyclists are present there may be a greater likelihood of collision with another bicyclist. As such, the estimated effect on injuries of a particular path characteristic may be explained by volume. In the matched analysis, we found that multi-use paths were associated with a reduction in the odds of a severe injury relative to sidewalks. Bicyclist volume could partially explain this observed association, but without information on bicyclist volume for each facility relative to the other (multi-use paths vs. sidewalks), the direction of the potential bias is difficult to determine. Others have also found that sidewalks are more dangerous for bicyclists compared with other facilities, and our parallel results make the issue of potential confounding by volume less concerning.

It has been reported that routes that are more aesthetically pleasing motivate people to bicycle.(**36**) If attractive routes increase the number of bicyclists, then any observed effect for aesthetic features may be at least partially explained by bicyclist volume. However, the only aesthetic elements that showed a significant association with injuries were verge maintenance and natural views, which are unlikely to be related to volume.

Another potential confounder worth mention was bicyclist experience. In our analysis, we focused on including potential confounders known to be risk factors for bicyclist injury, and while it may seem logical that experience would be related to injury outcomes, to our knowledge, there is no evidence of a direct relationship between experience and motor-vehicle collision or severe injury. Given the lack of evidence supporting such a relationship, as well as the limited number of variables our models could accommodate, we did not include experience as a potential confounder. We did examine whether previous bicycling experience at the location where the crash occurred (i.e., having bicycled there before vs. not) was related to either outcome, and did not find any evidence of an association. Previous experience at the location was judged to be the most appropriate measure of experience to examine since it most accurately represented "familiarity" with the site and its environmental characteristics. While experience was not included in the adjusted analysis we were able to adjust for age, which may act as a proxy for experience or years of bicycling. Future, larger studies should examine more closely the possibility of a relationship between experience and injury.

5.2.2 Selection Bias

Selection bias is a type of systematic error that results from the process used to recruit subjects into a study, or the process by which participants agree to be involved. It occurs when the association between exposure and outcome differs for those in the study sample versus those who are excluded.(**134**)

When bicyclists could not provide enough detail about the crash location for us to visit the site they were excluded. There was concern that these bicyclists may differ from those included in the sample, which could introduce selection bias. In order to examine this possibility, we compared the excluded bicyclists (controls) with the study sample. The most notable differences were that a higher proportion of excluded controls were 13-17 years old age, they had a lower proportion of helmet use, and a higher proportion of head injuries.

Because of these minor differences, it may be that there were fewer adolescents included in our sample than would have been included otherwise. Having adjusted for age in the analysis would have eliminated this concern. In light of the differences in helmet use and head injury between excluded controls and the study sample, it is necessary to consider how this difference may create selection bias. In order for selection bias to occur, helmet use (or head injury) would need to be related to characteristics of the environment (i.e., the exposure); yet the characteristics of the environment at excluded crash sites were unknown. Given that age is related to helmet use (**48, 49**), it may be that by considering age in the analysis, any effect of selection bias would be attenuated or removed. Since information on the environment at excluded crash locations was not available (i.e., we could not visit the sites due to shortage of information), it was not possible to determine whether or not the excluded sample differed in terms of environmental exposures. As such, we could not predict what the effect would be on a relationship between environment and motor-vehicle collision or severe injury. However, because excluded bicyclists made up a very small proportion of the overall sample, their inclusion/exclusion is unlikely to have had any major effect on the study findings.

Patients were recruited from 7 EDs in Calgary and Edmonton, Alberta. Since all patients suffered an injury that resulted in an ED visit, injured bicyclists who did not visit the ED were not captured. Both cities have other emergency care centers and injured bicyclists may have seen their family physician or a walk-in doctor. These bicyclists and their crash locations were not captured. Our sampling strategy could have created selection bias if those who did not visit the emergency department differed from those who did by exposure characteristics. It is possible that those injured while bicycling in rural areas, or in the suburbs at the outskirts of Calgary or Edmonton were less likely to visit one of the EDs, which tend to be located in proximity to the central core of the city. If so, then the environmental characteristics of these areas would have been under-represented in our sample, which could have resulted in an under-estimation of the potential effect of these characteristics or types of land use. It may also have resulted in an over-estimation of the effect of other characteristics or land use, for example, commercial land use. We cannot determine for certain if there were differences in the characteristics of crash sites between the study sample and those who were injured but did not visit the ED. The sites we observed were fairly spread out through each city, and it is likely that our sample adequately represented the distribution of environmental factors where injuries occur. In addition, our results for types of land use mirrored existing evidence, further reinforcing that our estimates were sound. It is likely that most motor-vehicle events and severe injuries result in an ED visit, and as a result, our sample allowed us to examine the characteristics of locations where these injuries occurred.

5.2.3 Misclassification Bias

5.2.3.1 SPACES Reliability Analysis

We conducted a comprehensive reliability assessment of the SPACES tool. This was integrated into the study in part because we wanted to ensure that the potential misclassification bias from knowledge of the case-control status of locations was addressed. We also wanted to add to the evidence on audit tool reliability by assessing the performance of the SPACES outside of the design phase, which has yet to be done.

The results of our assessment highlighted that types of land use appeared to be difficult to classify, particularly those with similar types of buildings, for example, services, offices, and retail. Items that required subjective assessment, such as attractiveness and difficulty for activities, consistently had lower κ values. In addition, items that required auditors to estimate numbers or distances had lower agreement (e.g., tree height, number of parking spots). In general, roadway characteristics demonstrated lower levels of reliability compared with land use and path characteristics, likely because the former included a greater number of subjective items.

Reliability assessment within auditor pairs suggested that pairs that had more training time with the primary research coordinator may have classified items more consistently. The analysis by case-control status showed that for motor-vehicle cases, inter-rater reliability was lower compared with controls. This could signal that observer bias was introduced when one auditor was not blinded. However, when examining reliability for severe cases and controls, the overall agreement ratings were nearly identical. The possibility of bias then was only a concern among the motor-vehicle group. The potential for differential misclassification bias was the primary reason for blinding at least one auditor whenever possible. The bias effect would have been an inflation of the estimated measure of association for an environmental characteristic. However, we used the blinded audit for the final analysis, thereby minimizing the potential for bias.

While our reliability assessment methodology differed slightly from the first SPACES reliability testing conducted by Pikora et al.(**95**), the results were comparable. Our findings were also similar to those for other audit instruments modelled on the SPACES.(**89, 96, 99**) When items were subjective in nature inter-rater reliability diminished in comparison with more objective items such as path and traffic characteristics. While others conducted reliability testing as part of the tool development process, we conducted our testing as part of a comprehensive case-control study. As such, our results may more accurately represent the reliability of the tool in application. Further, we identified limitations of concentrating on overall reliability, which can hide the presence of inconsistencies between rater pairs, or between different types of locations.

5.2.3.2 Recall Bias

We relied on the patient's recollection and description of the crash location to determine the audit sites. Some patients had trouble remembering the exact crash site, or their direction of travel at the time. The information they provided is subject to limitation of recall, especially if the patient was interviewed sometime after the injury event. Many interviews were conducted by telephone, and resources did not permit us to provide maps for patients to pinpoint their crash site. Some of the sites we observed may not have been the exact location of the event (e.g., one block difference, wrong side of the street). However, we did not visit sites where the crash description was too ambiguous, and made a concerted effort to collect as much detail about the crash location as the bicyclist could provide. We are confident that the sites audited were in fact the locations where injuries occurred.

It is possible that recall bias, especially regarding the crash location, was more widespread among controls than cases. Having been involved in a collision or serious injury event, cases may be more likely to remember details of the crash. This would result in differential misclassification bias, and could artificially suggest a relationship between certain characteristics and injury. It could also result in an attenuated estimated effect, if controls had more trouble recalling details of the crash or location. However, the results of this study did not produce unexpected effect estimates, and as such the potential for differential recall bias is not a serious concern.

5.2.3.3 Misclassification of Outcome

We relied on medical records and bicyclist narratives of the crash to classify study subjects into cases and controls. It is possible that bicyclists exaggerated the circumstances of their injury event. For example, a bicyclist involved in a “near hit or miss” could have reported that they were hit by a vehicle even if direct impact did not occur. These bicyclists would have been incorrectly classified as cases. This would have resulted in an over-estimation of the effect of the environmental characteristics of their crash sites. It is also possible that some hospitalizations were missed. If a patient was discharged from the ED, subsequently returned to the hospital, and was re-admitted on their second visit, we would not have captured that individual as a severely injured (i.e., hospitalized) case. We relied on ED records from the initial visit, which do not always include a record of re-admissions. In this scenario, cases would have been misclassified and enrolled as controls. This would have resulted in an underestimate of the effect of characteristics of the case crash sites. However, the screening and classification methods we used were rigorous. We ensured that the crash circumstances were recorded in detail, and elaborated if unclear by re-contacting patients. We also conducted detailed chart reviews when the discharge or injury information was unclear; this would have allowed us to determine if a patient was re-admitted, but only if the patient’s chart was reviewed a second time, after the initial ED injury and diagnosis information has been collected. Using these approaches, it is unlikely that cases or controls would have been misclassified.

5.2.3.4 Misclassification of Exposure

Summer is the time of the year where construction takes place, and it is possible that changes were made to sites between the crash and audit dates. Because of the large number of locations we visited, it was not possible to obtain records of work conducted for each site. We did record whether the site was under repair or in construction when the audits took place and examined if the bicyclists reported any work being done in their narrative description of the event. There was only 1 site where the path on side 1 was observed to be under repair and 1 site where the verge was undergoing maintenance. The bicyclists injured at these locations did not report any loose material, debris, or obstacles. If misclassification occurred because sites were modified between the crash and audit date, it would have resulted in an over-estimation of the effect of path condition. Since 80% of case audits and 75% of control audits were conducted within 2 months of the crash, it is unlikely that any extensive changes were done to the sites, and unlikely that path condition was misclassified.

We relied on subjective assessment of certain characteristics, such as garden maintenance, tree height, attractiveness, and difficulty for walking or bicycling. The accuracy of the information collected was subject to individual observer's opinions and may not be as reliable as if we had been able to use other more objective measures of assessment. In our comprehensive reliability analysis, despite that subjective items had lower agreement scores relative to objective measures, overall most had at least fair reliability ratings. It is unlikely that including these lower reliability items in the analysis had any bearing on the study results, especially since the results of the case-control reliability assessment showed the κ values for these items were similar for cases and controls. The advantage of being able to examine the potential effect of some of these subjective characteristics outweighs the potential for bias that may have been introduced if they were misclassified.

We used mechanical traffic counters to record the number of vehicles observed. Unfortunately, this made it challenging to count both directions of traffic at once at high volume sites. Our research assistants were taught how to use the counters, but were not trained in specific technical traffic counting methods. Our traffic counts may be subject to a small degree of over or under counting, most likely on the side of under-estimation. This could have translated into an under-estimate of the effect of traffic volume. But then, traffic volume was found to be significantly related to motor-vehicle events, and if its effect was diluted due to counting error, the true estimate would be even greater. While we could have used traffic information for the Cities of Calgary and Edmonton, this information would have been provided for a limited number of sites, which would have resulted in missing information for the majority of locations. Our approach allowed us to have this information for every site, making it possible to examine traffic as an independent predictor of injury.

5.2.4 Other Limitations

5.2.4.1 Power

Our initial sample size based on the information available at the time of the study design was 50 motor-vehicle cases and 50 severely injured cases. Anticipating a ratio of 1:3, we expected to audit 200 bicycling crash locations in each city, for a total of approximately 400 locations.

Due to a lower than expected number of bicycle injury ED visits, and difficulties contacting injured patients to enroll them, we were not able to meet our desired sample size. In addition, some controls were not time-matched. This resulted in a small sample for the matched analysis, and a corresponding loss of statistical power. For many environmental characteristics it was not possible to adjust for potential confounders because the number of discordant sets was low. We attempted to mitigate this limitation by conducting a second un-matched analysis which included all of the observed sites. This second examination was used for sensitivity analysis of the matched results, and the results of the two analysis methods were compared. In general, the same environmental factors were found to be significantly associated with the outcomes, with some differences in the size of the effect estimates. Conducting the study with a larger sample of matched sets would enhance the ability to detect "environmental" effects while maximizing the benefits of using a time/day-matched design.

5.2.4.2 Other Factors

We used data from Calgary and Edmonton, Alberta. These cities have similar layouts defined by river valleys through the central core and surrounding urban and subdivided neighbourhoods. Calgary's population is slightly greater, with 988,193 inhabitants in 2006, compared with 730,372 in Edmonton.(**135**) Calgary's population is also marginally more dense with a population density of 1,360.2/km^2, compared with 1,067.2/km^2 in Edmonton.(**135**) The results of this study may be transferrable to other North American metropolitan centers; however, differences in land-use mix, density, and city design may limit the generalizability to other contexts, such as Europe.

The weather in Calgary and Edmonton is quite variable. Weather conditions (e.g., rain, hail, snow) prevented us from visiting sites on the planned day/time on several occasions. Weather-delayed audits were conducted as soon as possible, but re-scheduling created a longer gap between the original crash date and the audit date. Weather may also have influenced the number of bicyclists or vehicles observed at the location.

We did not capture exposure data such as the number of kilometres bicycled on each type of infrastructure. Given the nature of the study design, the interview/audit process, and the lack of resources, this was not possible. This prevented us from evaluating injury rates on various types of infrastructure, or for certain characteristics (e.g., path markings). We did capture exposure data in the sense that we used non-motor-vehicle and non-hospitalized injured bicyclists to represent the exposure experience of the source population that produced the cases, allowing us to calculate odds ratios as relative rates in cases vs. controls. Future studies could improve on our design in this regard by capturing the bicyclist exposure data necessary to calculate injury rates proper.

5.3 Strengths

Case-control designs are well suited for studying relatively uncommon outcomes such as bicycling injuries.(**136, 137**) This type of design also makes it possible to examine more than one potential predictor of the outcome, and to explore interactions among factors. With this approach we were able to examine two outcomes; bicyclist-motor-vehicle collisions, and severe injuries. We used information on many potential predictors for each of these outcomes, providing a comprehensive analysis.

This study included a wide range of bicyclists such as children, commuters, and recreational riders. While many studies have focused on one particular subset, capturing information from people bicycling for a variety of reasons makes the findings of this study applicable to many different groups; this enhances the potential for the results to be integrated into city planning and public health and safety initiatives.

Robust data were collected. For example, several data collection tools were used that allowed us to capture comprehensive information at each site. The main tool, the SPACES, was a validated and reliable instrument.(**88, 95**) Combined with the other forms developed to capture additional information, our audit “kit” ensured all observations were thorough.

Focusing on micro-level characteristics of the injury locations enabled us to present detailed information on specific features that related to collision or severe injury. A number of studies have examined macro level neighbourhood features that contribute to physical activity or active transportation, particularly using GIS technology and mapping. These studies, however, have not linked specific environmental characteristics with injury, and have not been able to provide a more detailed examination. Our ability to pinpoint specific features at locations that increase or decrease injury risk is an asset for city planners, community organizations, and individuals. These people may use the information to address issues in specific locations, or to be aware of the risks in a particular area. Individuals can use this information to make sure they choose “safe” routes, and will be better prepared to make decisions about where/when to bicycle.

Chapter Six: Conclusions and Future Directions

What we know about personal risk factors for bicycling injury is extensive; and yet, these injuries remain an important concern worldwide. This leaves a gap in the state of our knowledge – what else might contribute to injuries beyond characteristics of the individual?

The natural and built environment where physical activity and active transportation occur cannot be overlooked, and creating safe, activity friendly environments is vital. This is ever important given the obesity epidemic we are facing, and the shift towards encouraging eco-friendly transportation.

This study has zeroed in on the micro-level features of the environment that may relate to bicycling injuries. As summarized in table 5.1, our findings point to specific elements that are risk factors for motor-vehicle collisions or severe injuries including traffic volume, types of land use, curb and path designs, and roadway features. Curb types, for example, are easily modifiable or can be considered when new communities are built or old sidewalks are replaced. Combined with current evidence on the risk associated with certain facilities such as sidewalks, our findings about traffic volume and roadway features reinforce the need to focus on developing designated bicycling facilities separated from traffic, while ensuring that these routes still allow bicyclists to reach key destinations. This will form the basis of the key recommendation emerging from this research; in order to ensure a greater level of safety, bicyclists need to be separated from vehicles. Where it is not possible to create separate, connected, off-road paths, on-road bicycle lanes should be delineated with a barrier, such as a cement divider. This type of design has already gained popularity in some Canadian cities, including Vancouver, BC, and Montréal, QC. With this information in hand, city and transportation planners will be better able to create environments that are safe and conducive to bicycling. Furthermore, by disseminating this information to direct end users, bicyclists will be aware of the dangers posed by certain features, enabling them to make safe route choices.

The findings of this study will be shared with our collaborators at the City of Calgary, the Calgary and Edmonton Police Services, the Alberta Bicycle Association, Bike Calgary, as well as injury prevention organizations including the Alberta Centre for Injury Control and Research (ACICR) and Safe Kids Canada. We have maintained regular contact with these groups over the course of the study, updating them on the data collection process and timelines. As we move forward, several strategies for dissemination have been proposed, and foremost, we will ensure that the information and recommendations we provide are presented in a user-friendly format. We will meet in-person (e.g., Ops and Cops meetings) with representatives of these groups to present the study results. Lay summaries will be developed to provide urban and transportation planners with succinct information on risk factors that should be taken into consideration when designing new facilities and making improvements to existing infrastructure. This information may also be integrated into the multi-model safety reviews conducted by the City of Calgary. It has been suggested that this type of information could also be included on publicly available (e.g., electronic) local bicycle maps. Bicycle advocacy groups have shown interest in adding this information to the curriculum of bicycle commuter courses (e.g., urban cycling skills course) and safe-cycling programs and brochures. With the help of Safe Kids Canada, we will create a media/press release to help disseminate this information to this organization's broad audience. We will also publish this study in peer-reviewed injury prevention and public health journals. These dissemination strategies have the potential to encourage researchers or other safe-cycling activists to undertake similar projects in other cities, allowing them to identify risk factors specific to their environment.

There are several roadway and bicycling facility designs that we were not able to examine in this study because they have yet to be implemented in Calgary and Edmonton. New bicycling facilities including bicycle tracks, bike boxes at intersections, and bicycle boulevards are promising developments that have already become popular in many European cities, and are beginning to appear in North America. The safety of these new facilities has yet to be examined, and future research should focus on determining the suitability of these designs. Future work should also build on the groundwork we have established, examining not only locations where injuries occur, but other sites that are popular among bicyclists, highlighting the features that draw people to certain areas. The framework of this study should be carried over to other cities, in order to identify context specific elements that relate to injuries; this way, bicycling will become safer, one city at a time. Have a good ride!

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APPENDIX A–Consent Forms

UNIVERSITY OF CALGARY

FACULTY OF MEDICINE
Department of Paediatrics, Alberta Children's Hospital

PARTICIPANT CONSENT FORM

TITLE: **What are the risk factors for cycling injuries?**

SPONSOR: **Alberta Heritage Foundation for Medical Research**

INVESTIGATORS:

Lead Calgary Investigator Dr. Brent Hagel
Assistant Professor
Paediatrics and Community Health Sciences
University of Calgary
Phone: (403) 955-7403

Lead Edmonton Investigator Dr. Brian Rowe
Professor and Research Director
Division of Emergency Medicine
University of Alberta
Phone: (780) 407-6707

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something written here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. You will receive a copy of this form.

BACKGROUND

Many people get hurt while riding a bicycle. Researchers in Calgary and Edmonton are interested in improving cyclist safety. We are asking you to be in this study because you were hurt while riding a bicycle. We plan to talk to over 3000 injured cyclists.

WHAT IS THE PURPOSE OF THE STUDY?

The study purpose is to find ways to prevent people from getting hurt while riding a bicycle. This will help us to make recommendations to prevent injuries in the future.

WHAT WOULD I HAVE TO DO?

If you agree, we will ask you some questions such as “how much do you cycle?”, “what clothing were you wearing when you got hurt?”, and “was your bicycle damaged?” This will take about 15 to 20 minutes. We will also look at your medical chart to see how badly you were hurt. Finally, if applicable, we may ask the police for information about what caused you to be injured.

During the three weeks after you were hurt, we may telephone you to make sure that we have the correct information about your injury.

WHAT ARE THE RISKS?

Answering these questions will not hurt you in any way. If you don’t want to be in the study it will not affect your medical care.

WILL I BENEFIT IF I TAKE PART?

There are no immediate benefits to you for being in this study. However, we hope your information will help us to find ways to prevent cyclists from getting hurt in the future.

DO I HAVE TO PARTICIPATE?

You don’t have to be in the study. You can quit at any time. No one will be upset if you decide not to participate. You should tell the doctor or nurse that you want to quit.

WILL I BE PAID FOR PARTICIPATING, OR DO I HAVE TO PAY FOR ANYTHING?

You will not be paid for participating in this study. Also, there are no costs to participate.

WILL MY RECORDS BE KEPT PRIVATE?

We will keep your information private. We will enter your information on a computer that is password protected. Any written information will be locked in a filing cabinet.. Only the researchers and the University of Calgary Office of Medical Bioethics may see your information. We will not include your name in any study reports. . No one except you, the doctor and the researchers will know that you participated in this study.

IF I SUFFER A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?

In the event that you suffer an injury as a result of participating in this research, no compensation will be provided to you by the University of Calgary, the Calgary Health Region, or the researchers. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

SIGNATURES

Your signature on this consent form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health care.

CONTACT NAMES AND TELEPHONE NUMBERS:

If you have questions about this research, please contact:

Dr. Brent Hagel, University of Calgary (403) 955 - 7403
or
Dr. Brian Rowe, University of Alberta (780) 407 - 6707

If you have any questions concerning your rights as a possible participant in this research, please contact The Ethics Resource Officer, Internal Awards and Research Services, University of Calgary, at 220-3782.

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

A signed copy of this consent form will be given to you to keep for your records and reference.

I agree to take part in the study.

Participant's Name	Signature and Date
Investigator/Delegate's Name	Signature and Date
Witness' Name	Signature and Date

UNIVERSITY OF
CALGARY

calgary health region
Alberta Children's Hospital

FACULTY OF MEDICINE
Department of Paediatrics, Alberta Children's Hospital

PEDIATRIC CONSENT FORM

TITLE: What are the risk factors for cycling injuries?

SPONSOR: Alberta Heritage Foundation for Medical Research

INVESTIGATORS:

Lead Calgary Investigator
Dr. Brent Hagel
Assistant Professor
Paediatrics and Community Health Sciences
University of Calgary
Phone: (403) 955-7403

Lead Edmonton Investigator
Dr. Brian Rowe
Professor and Research Director
Division of Emergency Medicine
University of Alberta
Phone: (780) 407-6707

This consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your child's participation will involve. If you would like more detail about something written here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. You will receive a copy of this form.

BACKGROUND

Many children get hurt while riding a bicycle. Researchers in Calgary and Edmonton are interested in improving cyclist safety. We are asking your child to be in this study because he or she was hurt while riding a bicycle. We plan to talk to over 3000 injured cyclists.

WHAT IS THE PURPOSE OF THE STUDY?

The study purpose is to find ways to prevent people from getting hurt while riding a bicycle. This will help us make recommendations to prevent injuries in the future

WHAT WOULD MY CHILD HAVE TO DO?

If you (and your child) agree, we will ask you some questions such as “how much do you cycle?”, “what clothing were you wearing when you got hurt?”, and “was your bicycle damaged?” This will take about 15 to 20 minutes. We will also look at your medical chart to see how badly you were hurt. Finally, if applicable, we may ask the police for information about what caused you to be injured.

During the three weeks after your child was hurt we may telephone you and your child to make sure that we have the correct information about your child’s injury.

WHAT ARE THE RISKS?

Answering these questions will not hurt your child in any way. If your child doesn’t want to be in the study it will not affect his or her medical care.

ARE THERE ANY BENEFITS FOR MY CHILD?

There are no immediate benefits to your child for being in this study. However, we hope your child’s information will help us to find ways to prevent cyclists from getting hurt in the future.

DOES MY CHILD HAVE TO PARTICIPATE?

Your child doesn’t have to be in the study and can quit at any time. No one will be mad if you or your child decides not to participate. You should tell the doctor or nurse that your child wants to quit.

WILL WE BE PAID FOR PARTICIPATING, OR DO WE HAVE TO PAY FOR ANYTHING?

Your child will not be paid for participating in this study. Also, there are no costs to participate.

WILL MY CHILD’S RECORDS BE KEPT PRIVATE?

We will keep your child’s information private. We will enter your child’s information on a computer that is password protected. Any written information will be locked in a filing cabinet. Only the researchers andthe University of Calgary Office of Medical Bioethics may see your child’s information. We will not include your child’s name in any study reports. No one except you, the doctor and the researchers will know that your child participated in this study.

IF MY CHILD SUFFERS A RESEARCH-RELATED INJURY, WILL WE BE COMPENSATED?

In the event that your child suffers an injury as a result of participating in this research, no compensation will be provided to you by the University of Calgary, the Calgary Health Region, or the researchers. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

SIGNATURES

Your signature on the consent form indicates that you have understood to your satisfaction the information regarding your child’s participation in the research project and agree to their participation as a subject. In no way does this waive your legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw your child from the study at any time without jeopardizing their health care.

CONTACT NAMES AND TELEPHONE NUMBERS:

If you have further questions concerning matters related to this research, please contact:

Dr. Brent Hagel, University of Calgary (403) 955 - 7403

If you have any questions concerning your rights as a possible participant in this research, please contact The Ethics Resource Officer, Internal Awards and Research Services, University of Calgary, at 220-3782.

Parent/Guardian's Name	Signature and Date
Child's Name	Signature and Date
Investigator/Delegate's Name	Signature and Date
Witness' Name	Signature and Date

The investigator or a member of the research team will, as appropriate, explain to your child the research and his or her involvement. They will seek your child's ongoing cooperation throughout the study.

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

A copy of this information sheet will be given to you to keep for your records and reference.

APPENDIX B-Cyclist Data Collection Form

Cyclist Data Collection Form 1

Interviewer Name: ________________________ Cyclist Initials: _________________

Date of Interview: ___ / ___ / _____ Start Time: ___________ Treatment Site: ______________
DD / MM / YEAR Finish Time: _________

Note to interviewer: Ask the injured cyclist (or proxy) the questions in SECTIONS 1 to 8. You will complete SECTION 9 with information from the injured cyclist's medical chart.

SECTION 1: CRASH DETAILS

1.1a What exactly happened in the crash? (Interviewer to write notes as the subject describes the crash)

____

____

____

____

1.1b What was the exact location of the crash? (ie. Street location, community, town/city) __________________

____

1.2 What time of day was the crash? __ __ : __ __ (00:00 - 23:59)

1.3 What was the date? ___/___/___ DD/MM/YEAR

1.4 What day of the week was it? (Circle number)

1 Monday	5 Friday
2 Tuesday	6 Saturday
3 Wednesday	7 Sunday
4 Thursday	8 Don't know

1.5 What was the weather like at the time of the crash? (Circle all that apply)

1 Clear	6 Snow
2 Cloudy/overcast	7 Fog/Smog/Smoke/Dust
3 Light rain	8 High Wind
4 Heavy rain	9 Other, please specify____________________
5 Hail/sleet	10 Don't know

1.6 What were the light conditions at the time of the crash? (Circle number)

1 Daylight
2 Sunglare (bright sun shining in eyes)
3 Dawn or dusk and street lights on
4 Dawn or dusk and no street lights on
7 Dawn or dusk and don't know about lights
5 Dark and street lights on
6 Dark and no street lights on
8 Dark and don't know about lights
9 Other, please specify____
10 Don't know

1.7 Where were you riding at the time of the crash? (Circle number)

1 Road	4 Offroad
2 Sidewalk	5 Other, please specify___________________________
3 Bike path	6 Don't know

1.8 On what kind of surface were you riding? (Circle all that apply)

1 Pavement	4 Grass
2 Gravel	5 Other, please specify ____________________________
3 Dirt	6 Don't know

1.9 What were the surface conditions at the time of the crash? (Circle all that apply)

1 Dry	5 Muddy
2 Wet	6 Hole/ruts/bumps
3 Slush/snow/ice	7 Other, please specify___________________________
4 Loose surface material	8 Don't know

1.10 Did something go wrong with your bicycle? (Circle all that apply)

1 The brakes didn't work	5 Something got caught in the spokes
2 The chain fell off	6 Other, please specify _________________________
3 A wheel fell off	7 Don't know
4 A tire went flat	8 Nothing went wrong with the bicycle

1.11 What type of crash was it? (Circle all that apply)

Non-motor vehicle related

- 2 Slid down/fell off bicycle – no vehicle involved
- 4 Impact with an animal
- 5 Impact with a pedestrian
- 6 Impact with another bicycle
- 10 Impact with a pole or tree
- 11 Impact with a street curb
- 12 Other, please specify ____

Motor vehicle related

- 1 Slid down/fell off bicycle – because of a vehicle (but no impact with the vehicle)
- 3 Impact with a parked or stationary vehicle
- 7 Impact with a moving car
- 8 Impact with a moving light truck or van
- 9 Impact with a moving bus or heavy truck
- 14 Other, please specify ____

13 Don't know

15 Refused to answer

1.12 Were you at any fault in the crash? (Circle number)

1 Yes	4 Don't know
2 No	5 Refused to answer
3 Partially	

1.13 How fast do you think you were going when you crashed? (Circle number)

1 I was stopped	5 15 to less than 20 km/hr
2 less than 5 km/hr	6 20 to less than 25 km/hr
3 5 to less than 10 km/hr)	7 25 km/hr and greater
4 10 to less than 15 km/hr	8 Don't know

1.14 What was the speed limit at the location of the crash?______ km/hour. [ ] Don't know [ ] No speed limit

1.15 Were you cycling faster than you typically would in similar conditions? (Circle number)

1 Yes	3 Don't know
2 No	4 Refused to answer

1.16 Approximately how many kilometers had you cycled that ride before you crashed?______Kms
[ ] Don't know

1.17 Did you use your brakes just before the crash occurred? (Circle number)

1 Yes	3 Don't' know
2 No	4 Other, please specify ______________________

1.18 What was your main reason for cycling at the time of the crash? (Circle number)
1 Going to/from work
2 Going to/from visiting friends or family
3 Going to/from a party or a bar
4 Cycling for fun or recreation/exercise
5 Going to/from shopping
6 Going to/from playing a sport
7 Going to/from school
8 Other, please specify ____
9 Don't know
10 Refused to answer

1.19 Had you previously cycled at the location of the crash? (Circle number)
1 Yes
2 No
3 Don't know

IF YES
1.20 In the last year how many times had you cycled at the location of the crash? (Circle number)

1 One to 3 times	4 More than 20 times
2 Four to 10 times	5 Don't know
3 Eleven to 20 times	

1.21 Was another person on your bicycle with you at the time of the crash? (i.e., were you "doubling" someone) (Circle number)
1 Yes
2 No
3 Don't know
4 Refused to answer

1.22 Were you riding with anyone else at the time of the crash? (Circle number)
1 Yes .... GO TO Question 1.23
2 No .... GO TO Question 1.26
3 Don't know .... GO TO Question 1.26

IF YES
1.23 Who were you riding with? (Circle number)
1 Children
2 Adults
3 Adults and children
4 Other, please specify _________________________

If cyclist is a CHILD (<18 years): ask 1.24 OR 1.25:

CHILD was riding with an adult (or adults and children):

1.24 Was the adult (or one of the adults) a parent or legal guardian? (Circle number)

1 Yes 3 Don't know
2 No 4 Other, please specify ______________________________

OR

CHILD was riding with another child (or children):

1.25 Were you being supervised (watched) by a parent or legal guardian who was nearby? (Circle number)

1 Yes 3 Don't know
2 No 4 Other, please specify ______________________________

1.26 Were you using any electronic devices while riding your bicycle? Such as…

1 An iPod, MP3 player, radio, walkman or other portable media device.......... GO TO 1.27
2 A cell phone or smart phone (e.g. a Blackberry)........... GO TO 1.28
3 A camera or video-camera
4 A GPS device
5 A bicycle computer
6 Other electronic device, please specify_____________________________
7 No
8 Don't know

1.27 Were you using noise cancelling headphones?

1 Yes, with both earpieces in
2 Yes, with one earpiece in
3 No
4 Other, please specify _____________________________________
5 Don't know

1.28 How were you using your cell phone at the time of the crash?

1 Having a conversation i.e. talking or listening
2 Checking voicemail
3 Checking for text messages
4 Reading a text/email message
5 Composing a text/email message
6 Hands-free use
7 Other, please specify _____________________________________
8 Don't know

SECTION 2: THE CYCLIST

2.1 Were you wearing a helmet? (Circle number)

1 Yes..... GO TO Question 2.2 3 Don't know .... GO TO Question 2.7
2 No ...... GO TO Question 2.7 4 Refused to answer ......GO TO Question 2.7

2.2 What type of helmet was it? (Circle number)

0 Bicycle, full face guard
1 Bicycle, no face guard
2 Other sport, please specify ______________________________________
3 Don't know

2.3 What was the main colour of your helmet?(write one colour) ____________

2.4 Would you say your helmet was light or dark? (Circle number)

1 Light 3 Don't know
2 Dark

2.5 How did the helmet fit you?

1 Excellent	4 Poor
2 Good	5 Don't know
3 Fair	6 Refused to answer

2.6 What happened to the helmet when you crashed?
1 The helmet stayed centred on my head
2 The helmet tilted backwards on my head
3 The helmet shifted to one side of my head.
4 The helmet came off
7 Other, please specify_______________________________
5 Don't know
6 Refused to answer

2.6a Was the helmet damaged in the crash? (circle all that apply)
1 The helmet cracked, but stayed in one piece
2 The helmet broke into pieces
3 The helmet was scraped or scratched
4 The visor broke
5 Other, please specify_____________________
6 Don't know
7 The helmet was not damaged

2.7 Were you wearing any clothing with reflective material? (Such as a jacket with reflective strips on the arms)
1 Yes .... GO TO Question 2.8
2 No .... GO TO Question 2.9
3 Don't know ... GO TO Question 2.9

2.8 Please describe the reflective clothing you were wearing.

REFLECTIVE CLOTHING DETAILS:

Type of clothing	Location of reflective material

2.9 Were you using any reflective articles that were not clothing? (Such as a reflector on a backpack or a reflector or light on your helmet)

1 Yes	3 Don't know
2 No	

IF YES, what were they and where were they located? ____
____
____

2.9a Were you using any other safety or protective articles? (Such as elbow pads, a chest protector, or shin guards)

1 Yes	3 Don't know
2 No	

IF YES, what were they?____

2.10 From the **front**, what was the main colour of clothing on your **upper** body (waist up)?________________

2.11 Was it light or dark? (Circle number)
1 Light 3 Don't know
2 Dark

2.12 Was it fluorescent? (Circle number)
1 Yes 3 Don't know
2 No

2.13 From the **back,** what was the main colour of clothing on your **upper** body (waist up)? __________

2.14 Was it light or dark? (Circle number)
1 Light 3 Don't know
2 Dark

2.15 Was it fluorescent? (Circle number)
1 Yes 3 Don't know
2 No

2.16 Were you wearing a backpack?
1 Yes ....GO TO Question 2.17
2 No..................GO TO Question 2.19
3 Don't know ....GO TO Question 2.19

2.17 IF YES, what colour was it? ______________________

2.18 Was it light or dark? (Circle number)
1 Light 3 Don't know
2 Dark

2.19 What was the **main** colour of clothing on your lower body (waist down)? __________________________

2.20 Was it light or dark? (Circle number)
1 Light 3 Don't know
2 Dark

2.21 Was it fluorescent? (Circle number)
1 Yes 3 Don't know
2 No

2.22 What were you wearing on your feet? (Circle number)
1 Nothing
5 Flip flops
2 Sports sandals
3 Light shoes (e.g. running shoes)
4 Heavy shoes/boots
6a Cycling shoes that were clipped in (attached to pedal)
6b Cycling shoes that were not clipped in
7 Other, please specify________________________
8 Don't know

2.23 Were you wearing gloves? (Circle number)
1 Yes 3 Don't know
2 No

SECTION 3: THE BICYCLE

3.1 Were you riding your own bicycle at the time of the crash? (Circle number)
1 Yes 3 Don't know
2 No 4 Refused to answer

3.2 Did the bicycle you were riding have training wheels? (Circle number)
1 Yes 3 Don't know
2 No

3.3 Was the bicycle damaged in the crash? (Circle number)
1 Yes 3 Don't know
2 No

3.4 What was the main colour of the bicycle?

3.5 Would you say it was light or dark? (Circle number)
1 Light 3 Don't know
2 Dark

3.6 Did the bicycle have any reflectors?

Front reflector?	☐ Yes	☐ No	☐ Don't know
Rear reflector?	☐ Yes	☐ No	☐ Don't know
Spoke reflector?	☐ Yes	☐ No	☐ Don't know
Pedal reflector?	☐ Yes	☐ No	☐ Don't know
3.7 Did the bicycle have a headlight?	☐ Yes	☐ No	☐ Don't know
IF YES: 3.8 Was the headlight turned on?	☐ Yes	☐ No	☐ Don't know
3.9 Did the bicycle have a taillight?	☐ Yes	☐ No	☐ Don't know
IF YES: 3.9a Was the taillight turned on?	☐ Yes	☐ No	☐ Don't know

SECTION 4: CYCLING EXPERIENCE

4.1 How many times have you ridden this specific bicycle? (Circle number)
1 Never ridden this bicycle before
2 Once or twice before
3 Three to five times before
4 Six to ten times before
5 More than ten times before

4.2a During the warmer months of the year, how often (on average) do you ride a bicycle? (Circle number)
1 Three days a week or more
2 One to 2 days a week
3 One to 3 days a month
4 Less than one day a month
5 Other, please specify ______________
6 Don't know
7 Not at all

4.2b During the colder months of the year, how often (on average) do you ride a bicycle? (Circle number)
1 Three days a week or more
2 One to 2 days a week
3 One to 3 days a month
4 Less than one day a month
5 Other, please specify ______________
6 Don't know
7 Not at all

4.3a During the warmer months of the year, how many kilometers (on average) do you ride a bicycle each week? (Circle number)

1 None	6 41 - 50 kms
2 10 kms or less	7 51 – 60 kms
3 11 – 20 kms	8 61 - 70 kms
4 21 – 30 kms	9 Other, please specify______________________
5 31 – 40 kms	10 Don't know

4.3b During the colder months of the year, how many kilometers (on average) do you ride a bicycle each week? (Circle number)

1 None	6 41 - 50 kms
2 10 kms or less	7 51 – 60 kms
3 11 – 20 kms	8 61 - 70 kms
4 21 – 30 kms	9 Other, please specify______________________
5 31 – 40 kms	10 Don't know

4.4 Do you have a job that requires you to ride a bicycle? (Circle number)

1 Yes	3 Don't know
2 No	4 Refused to answer

IF YES: 4.5 What is your job? ____

SECTION 5: OTHER FACTORS *(For children younger than 14 years old, omit questions 5.1 to 5.6)*

5.1 Did you drink any alcohol in the 12 hours before the crash? (Circle number)

1 Yes .... GO TO Question 5.2	4 Don't remember .... GO TO Question 5.5
2 No .... GO TO Question 5.5	5 Refused to answer ..... GO TO Question 5.5
3 Don't know .... GO TO Question 5.5	

IF YES: 5.2 How many hours before the crash did you **START** drinking? ____________________

5.3 How many hours before the crash did you **STOP** drinking? ____________________

5.4 What did you have to drink and how much?______________________________

____

5.5 Did you use any marijuana or other similar drugs in the 12 hours before the crash? (Circle number)

1 Yes ....GO TO Question 5.6	4 Don't remember ..... GO TO Question 5.7
2 No ....GO TO Question 5.7	5 Refused to answer .. GO TO Question 5.7
3 Don't know ... GO TO Question 5.7	

IF YES: 5.6 What drugs did you use and how much?______________________________

____

ASK OF ALL CYCLISTS:

5.7 Did you take any prescription or over-the-counter (non-prescription) medications in the 12 hours before the crash? (Circle number)

1 Yes, prescription medication(s) only
2 Yes, prescription medication(s) and over the counter medication(s)
3 Yes, over the counter medication(s) only
4 No
5 Don't know

IF YES: 5.8 What did you take and how much?______________________________________

____

SECTION 6: DEMOGRAPHIC INFORMATION

Begin by saying: "The following are some demographic questions. This information is valuable to our study, but you are not obligated to answer. Any information that you give us will be kept private."

6.1 Your sex: (Circle number)
1 Female
2 Male

6.2 What is your age? _____years

6.3 About how tall are you? _______________

6.4 About how much do you weigh? _____________

6.5 What ethnic group do you belong to? (Circle number)

1 Caucasian	5 African
2 Aboriginal	6 Other, please specify __________________________
3 Asian	7 Don't know
4 Hispanic	8 Refused to answer

Choose the appropriate column (adult or child cyclist) for questions 6.6 to 6.8

ADULT CYCLIST (18 years of age or older)	**CHILD CYCLIST** (Less than 18 years of age)
6.6 What is your level of education? 1 No high school diploma 2 High school diploma 3 College/professional diploma 4 Trade certificate (journeyman) 5 University degree 6 Graduate degree 7 Other, please specify_____________________ 8 Don't know 9 Refused	6.6 What is your mother's level of education? 1 No high school diploma 2 High school diploma 3 College/professional diploma 4 Trade certificate (journeyman) 5 University degree 6 Graduate degree 7 Other, please specify_____________________ 8 Don't know 9 Refused
6.7 What is the average annual income of your household? 1 Less than $30,000 2 Between $30,000 and $49,999 3 Between $50,000 and $69,999 4 $70,000 or more 5 Don't know 6 Not applicable 7 Refused to answer	6.7 What is the average annual income of your household? 1 Less than $30,000 2 Between $30,000 and $49,999 3 Between $50,000 and $69,999 4 $70,000 or more 5 Don't know 6 Not applicable 7 Refused to answer
6.8 What is your marital status? (circle number) 1 Single (never married) 2 Married 3 Living with a partner 4 Separated or divorced 5 Widowed 6 Refused to answer	

SECTION 7: PAST BICYCLE CRASHES

(For this study, a crash means that you fell off your bike with an injury or the bicycle was damaged)

7.1 In the last 5 years, how many crashes have you had as a cyclist? (not counting the present crash)__________

7.2 What was the year of your most recent crash? (not counting the present crash) ___________

7.3 Were you injured in the crash? (Circle number)
1 Yes .... GOTO Question 8.4
2 No .... GOTO Question 8.8
3 Don't know ...... GOTO Question 8.8

IF YES: 7.4 Did you seek medical care? (Circle number)
1 Yes 3 Don't know
2 No

IF YES:
7.5 Where did you receive medical care?
1 Emergency Department
2 Walk-in-clinic
3 Family Doctor
4 Other, please specify_______________
5 Don't know

7.6 Did this injury interfere with your normal daily activities? (Circle number)
1 Yes 3 Don't know
2 No

IF YES:
7.7 For how many days?__________________ DAYS

7.8 Was your bicycle damaged? (Circle number)
1 Yes 3 Don't know
2 No

SECTION 8: ATTITUDES AND BEHAVIOURS

The final section is about attitudes and behaviours. I will read two opinion statements. **Please choose the statement that is most like you**. There are no right or wrong answers; we simply want your opinion.

1 A I would like to try mountain climbing.
B I think people who do dangerous things like mountain climbing are foolish.

2 A I'd never do anything that's dangerous.
B I sometimes like to do things that are a little scary.

3 A I would like to try to water-ski.
B I wouldn't want to water-ski.

4 A I would like to try surf-board riding.
B I would not like to try surf-board riding.

5 A I don't like doing things that I'm not sure how to do and that are a bit scary.
B I don't mind trying fun things that I'm not sure how to do and that are a bit scary.

6 A I would like to try jumping from a plane with a parachute.
B I would never try jumping from a plane with a parachute.

7 A I like to do tricks and try new things when riding my bike, even if they could be a bit dangerous.
B When I ride my bike, I don't like doing tricks or anything that might be dangerous.

8 A I think skiing fast down a snowy mountain would be dangerous.
B I think it would be fun to ski really fast down a snowy mountain.

9 A I like to jump or dive off a diving board.
B I don't like the feeling I get when standing on a diving board.

10 A I like to swim in water that is not over my head.
B I like to swim in deep water that is over my head.

11 A Sailing on the ocean in a small boat would be dangerous and foolish.
B I think it would be fun to sail on the ocean in a small boat.

8.12 As we finish up, is there anything else about the crash that you would like included in the study? _______
____
____

8.13 May we contact you in the future to clarify any of the information you told us in this interview?
1 Yes ....Ask patient for the contact information below.
2 No………..Thank the patient for participating.

8.14 May we contact you about taking part in future research related to this study?
1 Yes ....Ask patient for the contact information below.
2 No………..Thank the patient for participating.

Name: ____
Telephone: ____
Best day and time to contact: ______________________________

SECTION 9: RESULT OF INJURY (To be collected from the patient's medical chart)

9.1 Please list all of the cyclist's injuries. Examples for each category are given below.

Injury	Nature of injury	Body part(s) involved
1		
2		
3		
4		
5		

NATURE OF INJURY

10 Superficial (e.g., bruise, abrasion)
11 Open wound/Laceration
27 Soft tissue
12 Fracture
13 Dislocation
75 Pulled elbow
14 Sprain or strain
15 Injury to nerve
16 Injury to blood vessel
17 Injury to muscle or tendon
18 Crushing injury
19 Traumatic amputation

20 Burn or corrosion
21 Frostbite
22 bite (with or without invenomation)
23 Electrical injury
24 Eye injury
25 Dental injury
26 Injury to internal organ

31 Foreign body in external eye
32 Foreign body in ear canal
33 Foreign body in nose
34 Foreign body in respiratory tract
35 Foreign body in alimentary tract
36 Foreign body in genito-urinary tract
37 Foreign body in soft tissue

41 Minor head injury
42 Concussion
43 Intracranial injury

50 Poisoning or toxic effect
51 Drowning or immersion
52 Asphyxia or other threat to breathing
53 Systemic over-exertion; heat/cold stress

60 Multiple injuries of more than one nature
70 No injury detected

BODY PART(S)

Head and Neck
110 Scalp, skull, head
120 Face (including ear)
130 Internal mouth
135 Specified head injury (specified by nature of injury)
140 Neck

Spine and Spinal Cord
200 Spine and/or spinal cord

Trunk
310 Thorax (incl. lungs, heart)
315 Upper back
321 Abdomen (incl. abdominal organs)
322 Lower back
323 Pelvis
324 Perineum and anogenital area

Shoulder and Arm
410 Shoulder
415 Clavicle
420 Upper arm
430 Elbow
440 Forearm
450 Wrist
460 Hand
470 Finger

Hip and Leg
510 Hip
520 Thigh
530 Knee
540 Lower leg
550 Ankle
560 Foot
570 Toe
700 Multiple injuries of more than one body part
900 Body part NOT REQUIRED (e.g. systemic injury, no injury detected)

9.2 Injury Severity Score: ________________________

9.2a Blood alcohol level (if applicable)_______________________

9.3 Patient Disposition (Outcome): (Circle number)

1 Left without being seen (LWBS)
2 Left against medical advice (LAMA)
3 Treated, follow-up PRN
4 Treated, follow-up required
5 Short stay unit, observation in emergency
6 Admitted to this hospital ☐ Ward ☐ ICU
7 Transferred to another hospital (specify) ____________________
8 Dead on arrival or died in emergency
9 Other, please specify ____________________________________

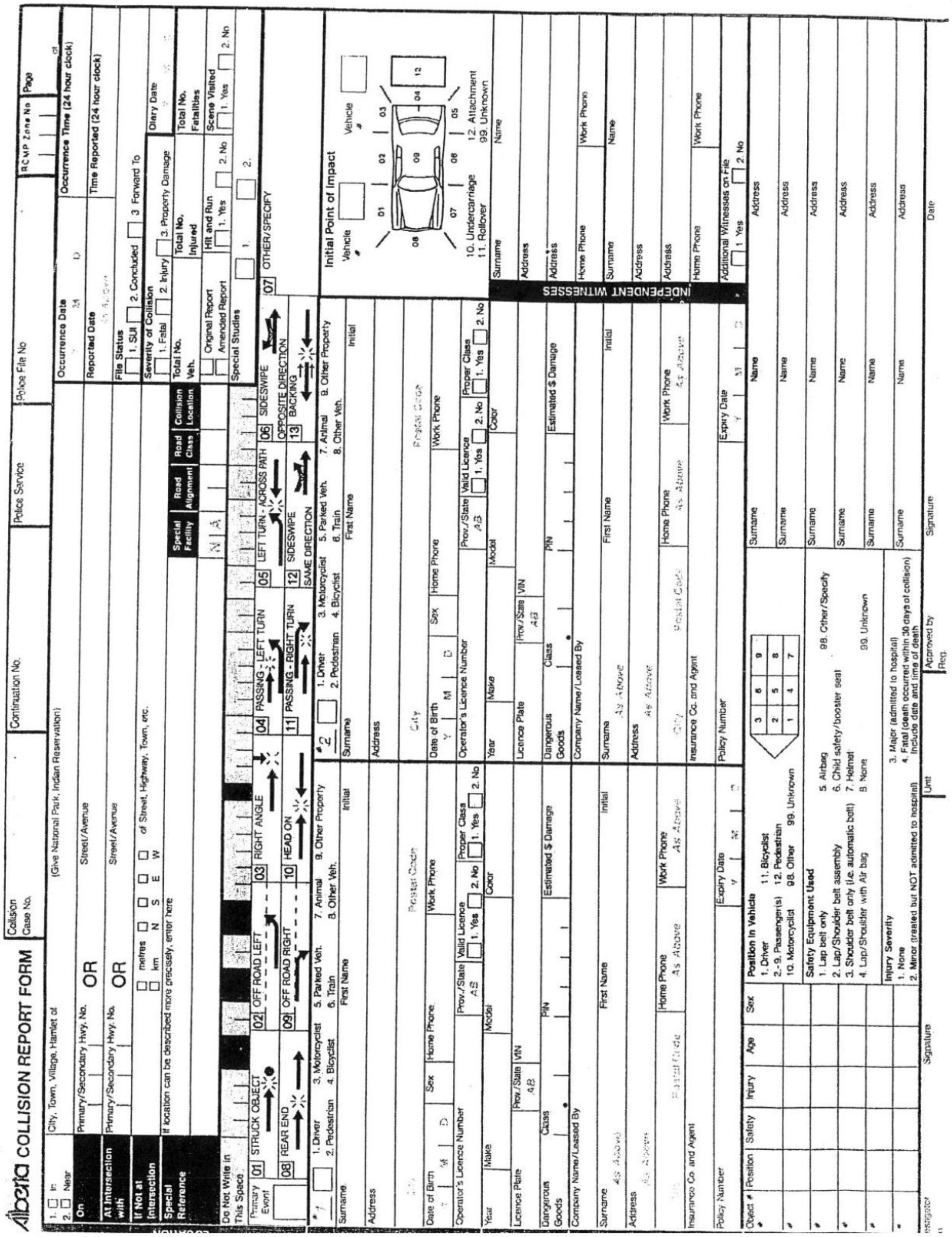
9.4 Questionnaire information obtained from (Circle all that apply)

1 Injured cyclist
2 Injured cyclist's parent or guardian
3 Other proxy respondent, please specify ______________________
4 Physician
5 Police officer
6 EMS worker

9.5 Place of Interview: (Circle number)

1 Emergency Department	3 Telephone
2 Hospital Inpatient Unit	4 Other, please specify __________

APPENDIX C-Alberta Collision Report



Alberta COLLISION REPORT FORM

Collision Case No. | Continuation No. | Police Service | Police File No. | RCMP Zone No. | Page ___ of ___

1. In / 2. Near — City, Town, Village, Hamlet of (Give National Park, Indian Reservation)

Occurrence Date Y M D | Occurrence Time (24 hour clock)

On — Primary/Secondary Hwy. No. OR Street/Avenue | Reported Date | Time Reported (24 hour clock)

At Intersection with — Primary/Secondary Hwy. No. OR Street/Avenue | File Status: 1. SUI, 2. Concluded, 3. Forward To

If Not at Intersection — metres / km, N S E W of Street, Highway, Town, etc. | Severity of Collision: 1. Fatal, 2. Injury, 3. Property Damage | Diary Date

Special Reference — If location can be described more precisely, enter here | Total No. Veh. | Total No. Injured | Total No. Fatalities

Do Not Write in This Space | Special Facility | Road Alignment | Road Class | Collision Location | Original Report / Amended Report | Hit and Run 1. Yes 2. No | Scene Visited 1. Yes 2. No | Special Studies 1. 2.

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/SPECIFY, 08 REAR END, 09 OFF ROAD RIGHT, 10 HEAD ON, 11 PASSING - RIGHT TURN, 12 SIDESWIPE SAME DIRECTION, 13 BACKING OPPOSITE DIRECTION

1. Driver, 2. Pedestrian, 3. Motorcyclist, 4. Bicyclist, 5. Parked Veh., 6. Train, 7. Animal, 8. Other Veh., 9. Other Property

Surname | First Name | Initial (for each of two vehicles)

Address | City | Postal Code

Date of Birth Y M D | Sex | Home Phone | Work Phone

Operator's Licence Number | Prov./State | Valid Licence 1. Yes 2. No | Proper Class 1. Yes 2. No

Year | Make | Model | Color

Licence Plate | Prov./State | VIN

Dangerous Goods | Class | PIN | Estimated $ Damage

Company Name/Leased By

Surname | First Name | Initial | Address | Home Phone | Work Phone

Insurance Co. and Agent | Policy Number | Expiry Date Y M

Initial Point of Impact — Vehicle # 01–12; 10. Undercarriage, 11. Rollover, 12. Attachment, 99. Unknown

INDEPENDENT WITNESSES — Surname | Name | Address | Home Phone | Work Phone

Additional Witnesses on File 1. Yes 2. No

Object # | Position | Safety | Injury | Age | Sex | Surname | Name | Address

Position in Vehicle: 1. Driver, 2.-9. Passenger(s), 10. Motorcyclist, 11. Bicyclist, 12. Pedestrian, 98. Other, 99. Unknown

Safety Equipment Used: 1. Lap belt only, 2. Lap/Shoulder belt assembly, 3. Shoulder belt only (i.e. automatic belt), 4. Lap/Shoulder with Air bag, 5. Airbag, 6. Child safety/booster seat, 7. Helmet, 8. None, 98. Other/Specify, 99. Unknown

Injury Severity: 1. None, 2. Minor (treated but NOT admitted to hospital), 3. Major (admitted to hospital), 4. Fatal (death occurred within 30 days of collision) Include date and time of death

Investigator | Signature | Unit | Approved by | Reg. | Signature | Date

COLLISION REPORT FORM | Case No.

Diagram: Use Solid Direction Lines Before Impact and Broken Lines After — North

Description: Include: Direction of Travel, Travelling Lane, Vehicle Movement, Obstructions, Fixed Object, Traffic Signs.

Proposed Police Action

Object Identification (1 2)
- 01. Passenger Car
- 02. Pick-Up/Van <4500kg
- 03. Mini-Van/MPV/SUV
- 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 Specify
- 99. Unknown

Driver Action (1 2)
- 01. Driving Properly
- 02. Stop Sign Violation
- 03. Yield Sign Violation
- 04. Fail To Yield ROW Uncontrolled
- 05. Fail To Yield ROW Pedestrian
- 06. Followed Too Closely
- 07. Parked Vehicle
- 08. Backed Unsafely
- 09. Left Turn Across Path
- 10. Improper Lane Change
- 11. Disobey Traffic Signal
- 12. Ran Off Road
- 13. Improper Turn
- 14. Left of Centre
- 15. Improper Passing
- 98. Other Specify
- 99. Unknown

Light Conditions (Choose one in A and one in B)

A (1 2)
- 01. Daylight
- 02. Sunglare
- 03. Darkness
- 99. Unknown

B (1 2)
- 01. No Artificial Light
- 02. Artificial Light
- 99. Unknown

Traffic Control Device (1 2)
- 01. None Present
- 02. Traffic Signal/Lights
- 03. Stop Sign
- 04. Yield Sign
- 05. Merge Sign
- 06. Pedestrian Cross-Walk
- 07. School Bus
- 08. Lane Control Signal
- 09. RR Crossing
- 98. Other Specify
- 99. Unknown

Traffic Control Condition (if applicable) (1 2)
- 01. Functioning
- 02. Not Functioning
- 03. Obscured
- 04. Missing
- 98. Other Specify
- 99. Unknown

Pedestrian Action (if applicable) (1 2)
- 01. Crossing With ROW
- 02. Crossing Without ROW
- 03. Walking/Working On Roadway
- 04. Getting On/Off Vehicle
- 98. Other Specify

Driver/Pedestrian Condition (1 2)
- 01. Apparently Normal
- 02. Had Been Drinking
- 03. Impaired By Alcohol
- 04. Impaired By Drugs
- 05. Fatigued/Asleep
- 06. Medical Defect
- 98. Other Specify
- 99. Unknown

Contributing Road Condition (1 2)
- 01. No Unusual Condition
- 02. Under Const./Maint.
- 03. Hole/Ruts/Bumps
- 04. Slippery When Wet
- 05. Oily Pavement
- 06. Soft/Sharp Shoulder
- 98. Other Specify
- 99. Unknown

Environmental Condition (Choose only one)
- 01. Clear
- 02. Raining
- 03. Hail/Sleet
- 04. Snow
- 05. Fog/Smog/Smoke/Dust
- 06. High Wind
- 98. Other Specify
- 99. Unknown

Surface Condition (Choose only one)
- 01. Dry
- 02. Wet
- 03. Slush/Snow/Ice
- 04. Loose Surface Mat.
- 05. Muddy
- 98. Other Specify
- 99. Unknown

Load Details (Choose one in A and one in B if applicable)

A (1 2)
- 01. Loaded
- 02. Unloaded
- 99. Unknown

B (1 2)
- 01. Load Not Spilled
- 02. Load Spilled
- 99. Unknown

Attachments (if applicable) (1 2)
- 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 W/O Pilot
- 98. Other Specify
- 99. Unknown

Trailer Type (if Attachments 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 Specify

Vehicle Condition/Contributing Factors
- 01. No Apparent Defect
- 02. Defective Brakes
- 03. Tires Failed
- 04. Improper Load/Shift
- 05. Lighting Defect
- 98. Other Specify
- 99. Unknown

Unsafe Speed (1 2)
- 01. Yes
- 02. No
- 99. Unknown - N/A

Vehicle Appears Repairable (1 2)
- 01. Yes
- 02. No
- 99. Unknown - N/A

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APPENDIX D-SPACES

SPACES FORM 1 ©2000

Auditor ID ________ Date ________
Suburb ________
Street ________
Seg ID ________

1a. Type of buildings/ features: *(tick all applicable)* (Side 1, Side 2)
Transport infrastructure 0 0
Housing 1 1
Office 2 2
Convenience stores 3 3
Other retail 4 4
Industrial 5 5
Educational 6 6
Service 7 7
Natural features 8 8

1b. Predominant buildings/ features: *(tick ONE per side only)* (Side 1, Side 2)
Transport infrastructure 0 0
Housing 1 1
Office 2 2
Convenience stores 3 3
Retail 4 4
Industrial 5 5
Educational 6 6
Service 7 7
Natural features 8 8

1c. Are the predominant buildings/features the same for both sides?
Yes 1
No 2

A. Path for walking &/or cycling: *(only if a path present)*

2. Type of path: (Side 1, Side 2)
Go to section B ← No path 1 1
Footpath 2 2
Shared path – with markings 3 3
Shared path – no markings 4 4

3. Path location: (Side 1, Side 2)
Next to road 1 1
Within 1m of kerb 2 2
Between 1 & 2m of kerb 3 3
Between 2 & 3m of kerb 4 4
More than 3m from kerb 5 5

4. Path material: (Side 1, Side 2)
Continuous concrete 1 1
Concrete slabs 2 2
Paving bricks 3 3
Gravel 4 4
Bitumen 5 5
Grass or sand 6 6
Under repair 7 7

5. Slope: (Side 1, Side 2)
Flat or gentle 1 1
Moderate slope 2 2
Steep slope 3 3

6. Path condition & smoothness: (Side 1, Side 2)
Poor (a lot of bumps, cracks, holes & weeds) 1 1
Moderate (some bumps, cracks, holes & weeds) 2 2
Good (very few bumps, cracks, holes & weeds) 3 3
Under repair 4 4

7. Permanent path obstructions: (Side 1, Side 2)
Poles 1 1
Signs 2 2
Tables & chairs 3 3
Trees 4 4
None 5 5

B On-road *(all segments)*
8. Path type:
On-road cycle lane – marked 1
On-road – no lane marked 2

9. Slope: *(only assess on-road if no path is present)*
Flat or gentle slope 1
Moderate slope 2
Steep slope 3

10. Condition of road:
Poor (a lot of bumps, cracks, holes) 1
Moderate (some bumps, cracks, holes) 2
Good (very few bumps, cracks, holes) 3
Under repair 4

11. Number of lanes on road (in total):
1 lane 1
2 or 3 lanes 2
4 or 5 lanes 3
6 or more lanes 4

12. Vehicle parking restriction signs present: (Side 1, Side 2)
Yes 1 1
No 2 2

13. Kerb type: (Side 1, Side 2)
Mountable 1 1
Non-mountable 2 2
No kerb 3 3

14. Traffic control devices: *(tick all applicable)*
Roundabouts 1
Speed humps or ramps 2
Chicanes, chokers, kerb extensions or lane narrowing 3
Traffic signals 4
None 5

15. Other routes available:
Lane 1
Access lane through cul-de-sac/no through road 2
Path through park 3
None 4

16. Type of crossings:
Zebra or children 1
Traffic signals 2
Bridge/overpass 3
Underpass 4
None 5

17. Crossing aids: *(tick all applicable)*
Median refuge or traffic island 1
Kerb extensions 2
None 3

18. Streetlights present? (Side 1, Side 2)
Yes 1 1
Go to Q20 ← No 2 2

19. Does lighting cover the path area? (Side 1, Side 2)
Yes 1 1
No 2 2

20. Are destinations present in segment?
Yes 1
Go to Q23 ← No 2

21. Number car parking facilities at destinations: *(approx.)*

	0 (1)	1-20 (2)	21-50 (3)	51-70 (4)	71-100 (5)	101+ (6)	
Shops							1
School							2
Other							3

22. Bike parking facilities:
Bike locker or enclosure 1
Bike parking or U rails 2
Rack or stand 3
None 4

23. Driveway crossovers:
Most buildings have one driveway 1
Approx. ½ buildings have one driveway 2
Approx ¼ buildings have one driveway 3
No driveways 4

24. Surveillance: (can be observed from a window, verandah, porch, garden)
Can be observed from more than 75% of buildings 1
Can be observed from between 50 – 74% of buildings 2
Can be observed from less than 50% of buildings 3
Not applicable 4

25. Garden maintenance: (well maintained – looks trim & clean, looks kept)
More than 75% well maintained 1
Between 50 –74% well maintained 2
Less than 50% well maintained 3
Not applicable 4

26. Verge maintenance: (well – looks trim & clean, looks kept)
More than 75% well maintained 1
Between 50 –74% well maintained 2
Less than 50% well maintained 3
Verge undergoing work 4
Not applicable 5

27. Number of verge trees: (Side 1, Side 2)
1 or more per house block 1 1
Approx. 1 tree for every 2 house blocks 2 2
Approx. 1 tree for every 3 or more house blocks 3 3
Go to Q29 ← No trees at all 4 4

28. Average height of trees: (Side 1, Side 2)
Small (head high) 1 1
Medium (between head & ceiling height) 2 2
Large (higher than a ceiling) 3 3

29. Cleanliness: (can you see any litter, rubbish, graffiti, broken glass, discarded items)
Yes lots 1
Yes some 2
None or almost none 3

30. Type of views: *(tick all applicable)*
Urban (houses & household gardens) 1
Commercial (shops, light industrial, offices, schools) 2
Water (such as river, ocean, lake) 3
Tended nature (parks, community gardens tended, well maintained) 4
Nature (parks, community gardens where level of care differs) 5

31. How alike are the building designs?
All of similar design 1
Range of different designs 2
Not applicable (no buildings) 3

32. How attractive would you rate this segment for walking?
Very attractive 1
Attractive 2
Not attractive at all 3

33. How physically difficult would you rate this segment for walking?
Easy 1
Moderately difficult 2
Very difficult 3

34. How attractive would you rate this segment for cycling?
Very attractive 1
Attractive 2
Not attractive at all 3

35. How physically difficult would you rate this segment for cycling?
Easy 1
Moderately difficult 2
Very difficult 3

C. OVERALL ASSESSMENT

Auditor ID ________ Date __________

Suburb ______________________________

Map ID ______________________________

36. Continuity of path

Path forms useful & direct route	☐	1
Path is disjointed	☐	2

37. Neighbourhood legibility – ease of finding your way around the neighbourhood

Very easy	☐	1
Fairly easy	☐	2
Not easy at all	☐	3

APPENDIX E-Additonal Audit

ID ________________________

Environmental Determinants of Cycling Injuries:
Additional environmental audit

Observer:___________________ Control site ☐ Calgary ☐
Case site☐ Edmonton ☐

Date: _______/ ______ / _____
Day Month Year

Location description: __________________________ ____________________________

<u>A. Path for walking &/or cycling</u>
36. Path width (cm):________________

5a. Intersection:
- N/A ☐
- Path/path ☐
- Path/road ☐
- Path/other:___________________

21a. Parking:
- N/A ☐
- On street parallel parking ☐
- On street angle parking ☐
- Parking lot (fill out 21) ☐
- Other: ________________________

5b. Kerb cuts:
- N/A ☐
- Kerb lip height (cm):____________

<u>Comments:</u>
Please write the question number, if the comment related to a specific item on the SPACES tool.

____
____
____
____
____
____
____
____

To be filled out from the cyclist interview if location is a case site only:

Type of error (check one only):
Mid-block ride out ☐
Cyclist inattention/error ☐
Driver inattention/error ☐
Other:____

APPENDIX F–Cyclist Flow Data Collection Form

ID________________________

Environmental Determinants of Cycling Injuries:
Cyclist Flow Data Collection Form

Observer initials:_____________ Control site ☐ Calgary ☐
Case site☐ Edmonton ☐

Date: ________/ _______ / ______
Day Month Year

Location description: ____________________________ ________________________________

Type of location (check all that apply):

☐ 1. School
☐ 2. Campuses (Universities/colleges)
☐ 3. Park/Recreation Area
☐ 4. Residential Area
☐ 5. Cycling Path
☐ 6. Roadway
☐ 7. Intersection
☐ 8. Bus stop
☐ 9. Parking lot
☐ 10. Other____________

Period 1 (15 min): _______to______ (24 hr) **"h" for helmet and ✓ for no helmet**

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Sum "h" period 1:______________

ID ___________________________

Period 2 (15 min): ______to_____ (24 hr) **"h" for helmet and ✓ for no helmet**

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Sum "h" period 2:_____________

APPENDIX G-Traffic Flow Data Collection Form

ID ________________________

Environmental Determinants of Cycling Injuries:
Traffic Flow Data Collection Form

Observer initials:_______ Control site ☐ Calgary ☐
Case site☐ Edmonton ☐

Date: _______/ ______ / _____
Day Month Year *Speed limit:*________ *Est avg. speed:*_________

Location description: ____

Type of location (check all that apply):

☐ 1. School
☐ 2. Campuses (Universities/colleges)
☐ 3. Park/Recreation Area
☐ 4. Residential Area
☐ 5. Cycling Path
☐ 6. Roadway
☐ 7. Intersection
☐ 8. Bus stop
☐ 9. Parking lot
☐ 10. Other_________

Period 1 (15 min): _______to______ (24 hr)

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110
111	112	113	114	115	116	117	118	119	120
121	122	123	124	125	126	127	128	129	130
131	132	133	134	135	136	137	138	139	140
141	142	143	144	145	146	147	148	149	150
151	152	153	154	155	156	157	158	159	160
161	162	163	164	165	166	167	168	169	170
171	172	173	174	175	176	177	178	179	180
181	182	183	184	185	186	187	188	189	190
191	192	193	194	195	196	197	198	199	200
201	202	203	204	205	206	207	208	209	210
211	212	213	214	215	216	217	218	219	220
221	222	223	224	225	226	227	228	229	230
231	232	233	234	235	236	237	238	239	240
241	242	243	244	245	246	247	248	249	250
251	252	253	254	255	256	257	258	259	260

ID ___________________________

261	262	263	264	265	266	267	268	269	270
271	272	273	274	275	276	277	278	279	280
281	282	283	284	285	286	287	288	289	290
291	292	293	294	295	296	297	298	299	300

Period 2 (15 min): _______to______ (24 hr)

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110
111	112	113	114	115	116	117	118	119	120
121	122	123	124	125	126	127	128	129	130
131	132	133	134	135	136	137	138	139	140
141	142	143	144	145	146	147	148	149	150
151	152	153	154	155	156	157	158	159	160
161	162	163	164	165	166	167	168	169	170
171	172	173	174	175	176	177	178	179	180
181	182	183	184	185	186	187	188	189	190
191	192	193	194	195	196	197	198	199	200
201	202	203	204	205	206	207	208	209	210
211	212	213	214	215	216	217	218	219	220
221	222	223	224	225	226	227	228	229	230
231	232	233	234	235	236	237	238	239	240
241	242	243	244	245	246	247	248	249	250
251	252	253	254	255	256	257	258	259	260
261	262	263	264	265	266	267	268	269	270
271	272	273	274	275	276	277	278	279	280
281	282	283	284	285	286	287	288	289	290
291	292	293	294	295	296	297	298	299	300

Traffic counting method (check one):

- Cyclist direction of travel ☐
- One direction per period ☐
- Both directions both periods ☐

APPENDIX H–Concerned Citizen Letter

UNIVERSITY OF
CALGARY

FACULTY OF MEDICINE
Department of Paediatrics, Alberta Children's Hospital

May 18, 2010

Dear Concerned Citizen:

The University of Calgary is doing a study on environmental risk factors for cycling injuries in Calgary and Edmonton. At various locations in each city, research assistants record information about the natural and physical characteristics of the area. The research assistants will also conduct traffic and cyclist counts at each location. This study will not negatively impact, or cause disturbances at the locations.

This study will provide important information on cycling injuries. If you have any questions, please feel free to contact me at 403-955-7403. You may also contact The Chair of the Conjoint Health Research Ethics Board at the Office of Medical Bioethics, 403-220-7990 or the Ethics Resource Officer, Internal Awards, Research Services, University of Calgary, at 403-220-3782.

Sincerely,

Brent Hagel, PhD
Assistant Professor
Paediatrics and Community Health Sciences
University of Calgary
C4-434, 2888 Shaganappi Trail NW
Calgary, AB
Canada T3B 6A8
Phone: 403-955-7403
Fax: 403-955-3055

APPENDIX I–Complete List of Missing Values

Variable	Severe Controls	Severe Cases	Total Severe	(%)	M-V Control	M-V Cases	Total M-V	(%)
High speed limit	18	1	19	8.02	15	4	19	8.02
High avg. speed	25	1	26	11.35	25	1	26	11.3
Side 1 path location	4	0	4	1.60	1	0	1	0.47
Side 1 path material	1	0	1	0.40	1	0	1	0.47
Side 2 type of path	1	0	1	0.38	0	1	1	0.43
Side 2 path location	5	0	5	2.66	1	1	2	1.22
Side 2 path material	1	0	1	0.53	1	0	1	0.61
Designated bicycle lane	3	1	4	1.69	3	1	4	1.69
Road slope	1	0	1	0.42	1	0	1	0.42
Many lanes	4	0	4	1.69	4	0	4	1.69
Any parking restrictions	0	1	1	0.42	0	1	1	0.42
Curb type	2	0	2	0.84	2	0	2	0.84
Traffic control devices	2	2	4	1.69	4	0	4	1.69
Crossings	3	1	4	1.69	3	1	4	1.69
Crossing aids	2	1	3	1.27	3	0	3	1.27
Other routes	15	1	16	5.84	5	0	5	2.11
Side 1 lights	3	0	3	1.09	1	0	1	0.42
Side 1 lights over path	3	0	3	1.09	1	0	1	0.42
Side 2 lights	6	0	6	2.19	3	0	3	1.27
Side 2 lights over path	4	0	4	2.06	1	0	1	0.42
Destinations	1	0	1	0.36	0	0	0	0.00
Driveways	1	0	1	0.36	0	0	0	0.00
High surveillance	0	0	0	0.00	0	0	0	0.00
High garden maintenance	2	0	2	0.79	2	0	2	0.84
High verge maintenance	1	0	1	0.83	1	0	1	0.87
Side 1 trees	5	1	6	2.99	4	1	5	2.87
Side 2 trees	4	1	5	2.59	3	1	4	2.40
Side 1 tall trees	3	0	3	1.21	0	1	1	0.47
Side 2 tall trees	3	0	3	1.21	0	2	2	0.95
Similar buildings	3	0	3	1.25	2	9	11	48.2
Continuity	7	0	7	2.56	7	0	7	2.97
Legibility	3	0	3	1.09	3	0	3	1.27
Intersection	8	0	8	2.92	6	0	6	2.53
Kerb cuts	0	0	0	0.00	0	0	0	0.00
Path width	9	2	11	4.01	10	1	11	7.91
Cyclists high speed	3	0	3	1.32	2	1	3	1.52
Riding faster than usual	1	0	1	0.39	0	1	1	0.45