The epidemiology of severe and fatal injury among Western Australian cyclists: a linked data analysis

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Abstract

Cycling offers a myriad of benefits, ranging from health and economic benefits to individuals, to environmental and urban sustainability benefits to the wider community. As a result, cycling has been actively encouraged by road transport and health agencies, and other government authorities. However, an increased number of cycling participants will likely result in the increased absolute level of injuries, possessing implications for health service use. The Australian National Road Safety Strategy 2011-2020, highlights the need for reliable and consistent road injury data in the effective monitoring of road trauma and progression toward achieving improved road safety outcomes. In Western Australia (WA), publically reported cycling injury statistics are derived from police reported road crash data. However, it has been suggested that police reported data may not sufficiently capture the true extent of cycling accidents and subsequent injury (even of more moderate or serious severity), resulting in a distorted view of cycling injury incidence and related burden on the health system in WA.

The overall aim of this study was to provide a comprehensive examination of severe and fatal cycling accident injuries which occurred in WA from 1995 to 2010, using linked population-level hospital admission, death and police-reported road crash data. While linked data have been used to examine road injury in WA in other studies, linked data have not previously been utilised as a means of specifically enumerating injury among vulnerable road users who are known to be underreported in police-reported road crash statistics, such as cyclists.

Aim 1 of this study aimed to quantify the incidence of cycling injury in WA by using hospitalisation and death records. The characteristics of cycling injury were examined in Aim 2 with descriptive analysis methods. Factors relating to the cyclist, injuries sustained, and geographical location of the cycling accident were investigated. The severity of injuries was also analysed, using the International Classification of Disease based Injury Severity Score (ICISS), from which a binary measure of 'killed and seriously injured' (KSI) was derived. The cohort was also linked to available police-reported road crash data, and additional factors relating to the circumstances of the accident were examined. Further analysis was also performed to compare differences between cycling injury characteristics between accidents which were and were not reported to police. Aim 3 used multivariate regression modelling to investigate predictive factors which led to a cyclist being KSI, by utilising the comprehensive data from all three data sources combined available to this study.

From 1995 to 2010, a total of 13,616 cases of cycling injury were recorded through hospital admission and/or death records. The majority of the cohort were male (80%), aged less than 18 years (59%), non-Indigenous (95%) and resided in the Perth metropolitan area (73%). Injuries to the head were most common, and fractures were the most common form of injury. The age-standardised rate of child cyclists injured declined over the 16 year study period, while the age-standardised rate of adult cyclists increased over the same time period. In terms of injury severity, 11% were classified as KSI, with adults 3% more likely to sustain injuries of greater severity than children.

Overall, non-traffic accidents (those not occurring on a public highway) accounted for the majority of cycling injury, although a decline was observed across the study period. However, the number of cycling accidents in traffic increased, driven by a 250% increase by adult cyclists. Non-collision accidents were the most common form of cycling accident, accounting for 66% of cycling injuries.

Of all cycling injury cases, only 1,373 (10.8%) cases had a linked police crash record. When compared to those without a linked crash record, cyclists with a crash record were generally older (63% aged 18 years and over, versus 38% of adults without a crash record), sustained more serious or fatal injury (34% versus 9%), had a longer length of hospital stay (8 days versus 3 days), and were more likely to be involved in an accident involving a car, pickup truck or van (82% versus 3%).

Among cases with a linked crash record, 83% of accidents were attended to by police and 93% of accidents involved at least one other vehicle. Spatial analysis of crash locations demonstrated that most cycling accidents occurred in the Perth metropolitan region, with a higher rate of overall injury in metropolitan WA compared to regional WA (4.7 vs 2.7 per 100,000 population) and KSI injury in metropolitan WA compared to regional WA (1.6 vs 1.0 per 100,000 population).

Multivariate regression analysis showed that males were at greater odds of being KSI than females (OR= 1.76, 95% CI: 1.43-2.16), and younger age groups were at lower odds of being KSI than older age groups. Abdominal injuries were at higher odds of being KSI than injuries to upper limbs (OR=13.1, 95% CI: 7.97-21.71). Cyclists who wore a helmet were 39% at lower odds (OR=0.61, 95% CI 0.47-0.81) of being KSI than cyclists who did not wear a helmet, after adjusting for age, gender and whether a motor vehicle was involved.

This study used administrative hospitalisation and death data to more accurately identify the cycling injury population in WA. Comparisons made between study sub-cohorts with and without police crash records demonstrate that the use of police records alone overlooks a vital proportion of injured cyclists, even among those with more severe injury – which is concerning given that WA's cycling statistics, strategies and policies, are based on these figures. The numbers of injured cyclists reported in this study were nearly nine-times higher than those in WA's published road crash statistics, which are based on police reports alone. Published statistics are likely to overlook sub-groups of the injured cycling population which make up the largest proportion of injuries – child cyclists, and cyclists involved in non-collisions, non- traffic accidents, and accidents of lower severity.

The findings from this study suggest that the use of data linkage is a feasible option for the reporting of cycling injuries in WA using hospital admission and death records, which are more reliable sources of injury and fatalities. The accessibility of linked data in WA facilitates regular reporting and as such, there is potential for linked data to be used for purposes such as routine state-wide road injury reporting. The quantification and analysis methods developed for this study can be readily adopted for other under-reported road user groups, such as pedestrians. The use of ICISS methodology also presents a standardised method for measuring injury severity which can be more reliably and consistently applied than police-reported measures.

In addition to methodological advances, this study provides a more detailed examination of cycling injury severity than previous published work. It has provided insight for the better understanding of factors which contribute to cycling injuries leading to hospitalisation and fatality in WA, and factors which increase the severity of cycling injuries.

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List of Abbreviations

ABS	Australian Bureau of Statistics
ACHI	Australian Classification of Health Interventions and Australian Coding Standards
ACS	Australian Coding Standards
AIS	Abbreviated Injury Score
ASR	Age Standardised Rate
CI	Confidence Interval
GDA	Geocentric Datum of Australia
GIS	Geographic Information System
ED	Emergency Department
EDDC	Emergency Department Data Collection
ERP	Estimated Resident Population
EU	European Union
HMDC	Hospital Morbidity Data Collection
ICU	Intensive Care Unit
ICD	International Classification of Diseases
ICD-9-CM	International Classification of Diseases, Version 9, Clinical Modification
ICD-10-AM	International Classification of Diseases, Version 10, Australian Modification
ICISS	International Classification of Disease based Injury Severity Scaling
IRIS	Integrated Road Information System
ISS	Injury Severity Score

KSI	Killed and Seriously Injured
KSI-RSC	Killed and Seriously Injured – Road Safety Commission
LGA	Local Government Authority
LOS	Length of Stay
MRWA	Main Roads Western Australia
NISS	New Injury Severity Score
OCRF	Online Crash Report Facility
OECD	Organisation for Economic Co-operation and Development
OR	Odds Ratio
PBN	Perth Bicycle Network
PSP	Principal Shared Paths
RSC	Road Safety Commission
RR	Rate Ratio
RRCWA	Reported Road Crashes in WA
SD	Standard Deviation
SRR	Survival Risk Ratio
WA	Western Australia
WADLB	Western Australian Data Linkage Branch
WADLS	Western Australian Data Linkage System
WA DOH	Western Australian Department of Health
WHO	World Health Organisation

Chapter 1 Introduction

1.1 Study context and rationale

Attitudes towards cycling varies across different countries. The use of bicycles in developing countries such as China and India as a form of transport are borne out of necessity and affordability, in comparison to developed countries such as the United Kingdom, United States and Australia, where the transportation system is dominated by motor vehicles and cycling is primarily viewed as a leisure or recreational activity.[1] In a time when cities are growing in size and population, cycling could be the answer to urban transportation systems which are rapidly becoming unsustainable and inefficient with increasing carbon footprint. Cycling also offers a means to address the rising obesity epidemic seen in developed countries through a form of physical activity that can be enjoyed in both transportation and recreational settings. The benefits of cycling as a means to relieve pressures of congestion, and improve the efficiency and accessibility of modern cities were formally recognised in 2015, when 28 member states of the European Union (EU), which includes countries with the highest cycling participation rates in the world, signed the 'Declaration of Luxembourg'. This agreement aims to promote cycling as an environmentally friendly and efficient mode of transport, through the development of strategies to increase cycling participation and establish cycling infrastructure to strengthen cycling networks across the EU.[2] The recognition of cycling benefits is also increasing in Australia, with all jurisdictions encouraging the increase in cycling participation.[3]

However, with an increase in the number of cyclists, there will inevitably be an increase in the number of crashes involving cyclists resulting in injury. In Western Australia (WA), publically reported cycling injury statistics are derived from police reported road crash data.[4] However, it has been suggested that police reported data may not sufficiently capture cycling accidents and subsequent injury, resulting in a distorted view of cycling injury incidence in WA.[5, 6] This reflects concerns raised in the National Road Safety Strategy 2011-2020, which highlighted that access to comprehensive data and empirical evidence is key to reducing the burden of road trauma.[7]

Cycling injury is a multifaceted problem, caused by various factors ranging from behavioural factors relating to road awareness and education among cyclists and other road users, to environmental factors relating to the road infrastructure and environmental circumstances. In turn, the severity of sustained injuries is also dependent on multiple factors. If cycling injury information is inadequate, the identification of factors resulting in cycling injury in WA, and the interplay between them, cannot be sufficiently understood.

Furthermore, the risk of injury from cycling affects the uptake of cycling – if cycling is perceived to be an unsafe activity, non-cyclists are likely to be discouraged from partaking.[8] Therefore an important aspect in the encouragement of greater participation lies in adequately investigating the causes of cycling injury, in order to implement injury prevention strategies to make cycling a safer activity.

1.2 Study aim

The overall aim of this study was to provide a comprehensive review of severe and fatal cycling accidents which occurred in WA from 1995 to 2010, using whole-population linked data methods. By using multiple sources of routinely-collected cycling injury information, this study addressed the need for a review of cycling injury in WA beyond only cycling accidents reported to police, in addition to enabling the study of a greater number of factors contributing to injury among cyclists.

The specific aims of this study were formulated to address the fundamental tenets of descriptive epidemiology – person, place and time – in the context of injury among cyclists in WA. The descriptive nature of Aims 1 and 2 directly examine these concepts, while Aim 3 looks to further explore predictors of injury severity. Aims 2 and 3 were further broken down into objectives, to specifically examine particular aspects of each respective aim.

Aim 1. **To quantify levels of severe and fatal cycling injury in WA, based on hospital and death data: 1995-2010**

Aim 2. **To characterise severe and fatal cycling injury in WA in terms of sociodemographic, injury type, accident type and geo-spatial factors: 1995-2010**

Objective 2a. *To characterise cyclist, injury and accident related factors in severe and fatal cycling injury*

Objective 2b. *To characterise differences in severe and fatal cycling injury between cases with and without police-reported crash records*

Objective 2c. *To describe accident and geo-spatial characteristics of severe and fatal cycling injury, based on police-reported crash records*

Aim 3. **To determine risk factors for being killed or seriously injured (KSI) in cycling accidents in WA: 1995-2010**

Objective 3a. *To examine predictors of being KSI among severe and fatally injured cyclists*

Objective 3b. *To examine predictors of being KSI among severe and fatally injured cyclists in a police-reported accident*

1.3 Demarcation of scope

In this study, a 'severe or fatal cycling accident injury' was defined as an injury resulting in a hospital admission or fatality, caused by a transport accident while using a vehicle operated solely by pedal, which includes bicycles, tricycles or other pedal cycles. Severe or fatal cycling accident injuries were referred to as 'cycling injury' throughout this thesis for brevity. Vehicles which are operated by persons sustaining cycling injuries were referred to as 'pedal cycles' throughout this study, consistent with the terminology used in the International Classification of Diseases (ICD) coding classification.[9, 10] A transport accident is defined according to the ICD as:

> "any accident involving a device designed primarily for, or being used at the time primarily for, conveying persons or goods from one place to another".[10]

These accidents include both on-road and off-road cycling, and includes both recreational and commuter-type cycling.

Injury resulting from non-accidental or non-transport means were excluded from this study, i.e., injuries resulting from events unrelated to the means of transportation (e.g. fingers crushed in closing car doors), injuries to persons engaged in the maintenance or repair of transport equipment or a vehicle not in motion (unless the person was injured by another vehicle in motion), assault, events of undetermined intent, or intentional self-harm.

Cycling injuries which resulted in admission to hospital or death in WA were included in this study, as confirmed through a Western Australian hospital separation or death record, regardless of whether they also had a corresponding traffic crash record. Cycling injuries where hospital admission or death occurred outside of WA were not examined in this study.

Injured cyclists presenting to primary health care providers, or emergency department (ED) presentations which did not lead to inpatient admission, were not within scope for this study, as these injuries were considered to be of lower severity. As this study focussed on cycling injury, rather than cycling crash events, cycling accidents not resulting in injury were beyond the scope of the current study.

1.4 Thesis structure

To provide context to the issue of cycling injury, the next chapter (Chapter Two) describes cycling participation levels in Australia and WA, including a summary of strategies by Governments and health agencies used to encourage the uptake of cycling. The chapter also reviews and critiques the relevant literature in the field of cycling injury, with particular focus on cyclist, injury and accident characteristics, and research methods used in empirical studies of these areas.

Chapter Three presents the overall methods used in this study. Data linkage processes and data sources are described, as are the data preparation methodologies which were employed to analyse data sourced from multiple datasets. Methods used to derive measures of injury severity from the available data are detailed. Methods specific to each study aim are also described, including statistical analyses and spatial analytic approaches.

Results are presented in Chapter Four, which is divided into three sections; one for each study aim. Results for each aim are divided into subsections relating to study objectives which further examine each aim.

Chapter Five discusses the main findings, in comparison to other studies and also details the study limitations and strengths. The implications of the results of this study for injury prevention and road safety research, policy and practice are highlighted, and concludes with recommendations for future research.

Chapter Six summarises the key areas of interest arising from this study, including the significance of findings and relevance to the community, and how results can directly be applied and translated into policy.

1.5 Significance of this study

This study investigated cycling injury with a methodology which enables analysis of injury severity across multiple administratively-collected data sources, in a manner which has not been widely explored in road injury studies in WA to date. Research studies examining cycling injury in WA have been performed in the 1990s[6] and early 2000s,[11, 12] however the availability of more recent linked health and crash data facilitates the analysis of updated information to generate more up-to-date findings applicable to current injury prevention and road safety strategies. This study also extended road safety work conducted by the Department of Health WA,[13, 14] by applying established injury severity methods to specifically examine injury among cyclists.

The approaches taken in the current study add to the knowledge of severity of road injury in WA and sets the foundation for future uses of linked data for road injury research. It is expected that the findings will have national and international implications in the fields of road safety and injury prevention, as the methodology utilised in this study is not known to have been applied to determine cycling injury incidence in Australia or internationally. In addition to providing new knowledge of cycling injury, the findings from this study will assist in reducing areas of risk and rates of injury, extending to a reduced burden of injury, creating a safer environment to encourage physical activity in the community. The findings will also inform policy on urban design, and support public health initiatives such as cycling promotion campaigns.

This study supports existing strategies to increase cycling participation, and contributes to policy and practice to encourage safer use of WA roads while preventing injury among vulnerable road user groups. Through the unique study design, this study provided more accurate characterisation of injured cyclists allowing better appreciation of the needs of this road user group by using more extensive and more recent data than previous studies. This study analysed trends over a longer period of time than previous studies, and incorporated geographic factors into the analysis. This study also identified predictors for severe and fatal injury, which will facilitate the development of strategies to reduce the risk of severe and fatal injury in cyclists.

Chapter 2 Literature Review

2.1 Chapter overview

This chapter reviews the literature relating to cycling participation and cycling injury, to provide context for this study from both an injury prevention and road safety standpoint. The key areas examined are:

(i) Cycling context – the benefits of cycling to individuals and the community are outlined. The case for encouraging increased uptake of cycling is presented, including demonstrated commitment from all levels of government to fund and support cycling promotion and cycling injury prevention initiatives.

(ii) Cycling participation – levels of cycling participation in Australia and WA are detailed. Barriers to cycling uptake are also explored, to identify perceived and actual risks to cyclists, and how these might be addressed to encourage cycling participation.

(iii) Cycling injury – current levels of cycling injury in Australia and WA are outlined, and research describing cycling injury characteristics is reviewed and critiqued.

(iv) Cycling injury research methods – as sources of information used to report cycling accident injury can differ, the challenges of reporting cycling injury and measurement of injury severity are explored.

(v) Characteristics of cycling injury – accident and injury characteristics reported from previous research studies are examined.

This review will identify gaps in current knowledge of cycling injury in WA, setting the foundation for the research reported in this thesis.

2.2 Cycling context

2.2.1 The benefits of cycling

2.2.1.1 Health benefits

The benefits of physical activity are widely known and well documented. There is evidence for an association between regular physical activity and decreased mortality, cardiovascular disease, obesity, cancer and depression.[15-17] Studies suggest that levels of childhood physical activity may also influence physical activity levels in adulthood, [18] and findings have suggested a strong relationship between physical activity and reduced levels of obesity in children.[19, 20] Therefore, physically active children are at reduced risk of developing health conditions such as cardiovascular disease as adults,[21] and thus it is important to encourage and promote physically active behaviours and lifestyles from a young age. Research has also demonstrated that physical activity is associated with positive mental health outcomes.[22-24] It has been hypothesised that the improvement in mental health conditions such as depression through increased physical activity are linked to physiological pathways, for example, the activation of endorphin secretion, producing euphoric sensations[25] and the increase of endocannabinoids which alter cognitive processes.[26]

Cycling is a low-impact form of activity which can be participated in as a recreational activity or as a means of transportation.[27] As such, cycling has been recognised as a physical activity which has strong potential to promote public health.[15] Active transportation, or active commuting, by means which include cycling have been shown to improve health outcomes.[28, 29] There is strong evidence which links active transportation by cycling with benefits to cardiorespiratory fitness,[30-32] reduced obesity,[29, 33, 34] cardiovascular disease,[28, 35, 36] stroke,[37] diabetes[38] and all-cause mortality.[16, 39] Research from the United Kingdom has also found that cyclists who cycle 40 kilometres or more per week halve their risk of developing heart disease, compared to people who do not cycle.[40] Mental health benefits have previously been attributed to active commuting in the form of walking and cycling.[15, 41, 42] A qualitative study by Zander [43] concluded that cycling improved quality of life among older cyclists, and cycling has also been demonstrated to encourage people to feel more connected with their community and environment, through being physically engaged and present in the community.[44, 45]

Exposure to traffic congestion has been associated with reduced health, work performance and overall satisfaction with life among individuals, and is associated with stress, increased blood pressure and aggressive behaviour.[46, 47] Cycling has the potential to circumvent some of these issues through the avoidance of traffic congestion while commuting, although little research has focussed on this issue to date. Despite concerns that there may be health risks to cyclists due to increased exposure to air pollutants and risk of injury, the benefit of increased physical activity and subsequent positive health outcomes have been shown to outweigh these risks.[48] Research suggests that through cycling, an individual gains approximately nine-times more life-years through improved health outcomes, counterbalancing the number of life-years lost due to increased inhaled air pollution and traffic accidents.[49]

2.2.1.2 Economic and environmental benefits

Improved health outcomes from cycling are likely to lead to reduced healthcare costs in the longer term.[27] The economic cost of physical inactivity in Australia was estimated to be $1.5 billion in 2006/07.[50] At a population level, cycling provides a sustainable opportunity to improve the physical activity of Australians while lowering the cost burden of physical inactivity and associated health conditions, and reducing health care costs. A study commissioned by the Queensland Government estimated that for each person who cycled 20 minutes to work and back instead of using a motor vehicle, the economy benefits by AU$14.30, through a culmination of health, traffic decongestion, infrastructure and environmental benefits.[51] In 2008, the estimated value of cycling participation to the Australian health system was $227.2 million per annum.[52]

In addition to benefits to the health economy, cycling offers economic benefits to individuals. As a method of transport, cycling offers an effective and cheaper personal transportation alternative to motor vehicles. With improved technology, and the increase in demand leading to economies of scale, the average cost of pedal cycles have decreased over time, making cycling more accessible to the general population.[53] Additionally, pedal cycles offer a transport alternative to motor vehicles with no fuel or vehicle registration costs, with commuter cyclists estimated to have collectively saved $35 million in fuel costs per year in Australia.[54] There are also lower servicing and maintenance costs and reduced parking and storage requirements associated with cycling, compared to owning a motor vehicle.

In urban environments where trip distances tend to be shorter, pedal cycles offer a cost-effective travel means, which can often be a faster mode of transport compared to motor vehicles, particularly in areas of higher urban density.[2] From an infrastructure point of view, the construction of cycling infrastructure only costs a fraction of the infrastructure for motor vehicles and public transport. For example, one car parking space can store multiple pedal cycles. These factors combine to make urban cities more accessible and connected, contributing to economic growth and development and more sustainable cities.[54, 55]

Cycling is one of the most environmentally-friendly modes of transport, when production, fuel and maintenance costs are considered. As a form of transport that produces no carbon emissions, cycling reduces transport emissions, reduces noise pollution and improves air quality in neighbourhoods.[44, 52] The benefits of reduced congestion as a result of cycling uptake in Australia have been estimated at $63.9 million per annum while greenhouse gas emission savings alone have been estimated at $9.3 million.[52]

2.2.2 Government support

Given the positive effects to individuals and the broader community, cycling participation is widely encouraged in Australia.[3, 44, 56-60] Federal and state government authorities proactively support the increase in cycling participation and long-term sustainability of cycling by investing substantial funds into cycling infrastructure and developing cycling strategies to encourage its uptake. Government initiatives are developed in tandem with road safety authorities and injury prevention groups to capitalise on industry knowledge in the development of effective approaches.[61]

2.2.2.1 Financial investment

In the financial years 2010-11 to 2013-14, Australian States and Territories collectively invested $399.4 million in cycling infrastructure.[62] Over the past seven years, the WA State Government alone has invested $112.8 million in cycling networks in WA, which has resulted in the construction of 246 kilometres of off-road shared paths and 74 kilometres of on-road bike lanes.[63] In 2014, the WA Department of Transport spent $300,000 on the ‘Share Our Roads’ campaign, which aimed to promote, educate and inform Western Australians in regard to motorist and cyclist safety to encourage the sharing of the roads.[64] In 2015, the WA State Government announced a further $75 million investment into cycling, including $27 million to improve the cycling network by 2019.[63]

2.2.2.2 Strategies and policies

There are a number of current national and state-wide strategies which directly relate to the encouragement of cycling in Australia and WA:

- ***National Cycling Strategy 2011-2016:*** The overall aim of the Australian National Cycling Strategy is to increase the number of cyclists in Australia, and improve perception and attitudes toward cycling. The six objectives of this Strategy focus on cycling promotion, infrastructure and facilities, integrated planning, safety, monitoring and evaluation, and best practice guidance.[3] The Strategy has been endorsed by Ministers of Transport, Infrastructure and Road Safety from all Australian states and territories.

- ***Western Australian Bicycle Network Plan 2014-2031:*** The WA strategic bicycle network plan was launched in March 2014 by the WA Department of Transport, and is aligned with the *National Cycling Strategy 2011-2016*. It aims to build evidence and demonstrate the benefits of cycling for the community; encourage cycling to build active and healthy communities; provide a high-quality, interconnected bicycle network; improve the level of safety for people cycling; and build and enhance relationships with advocacy groups and stakeholders.[58]

- ***Western Australian Mountain Bike Strategy 2015-2020:*** This Strategy was launched in June 2015 by the WA Department of Sport and Recreation and aims to support recreational mountain biking activity, which is rapidly growing in popularity. Almost 120,000 mountain bikes are purchased per year in WA, with 19% of Western Australians owning a mountain bike.[65] This strategy aims to increase mountain bike participation, develop trails, facilities and infrastructure, develop economic sustainability in the resourcing of this activity, and raise the profile of this activity for the recreation, sport and tourism industries.[65]

The above strategies support other national and state-wide initiatives including, but not limited to, those relating to road safety, active transportation, injury prevention, the development of sustainable and liveable communities (including appropriate transport infrastructure), and the encouragement of physical activity:

- Directions 2031 and Beyond[66]
- National Road Safety Strategy 2011-2020[7]
- National Injury Prevention and Safety Promotion Plan 2004-2014[67]

- National Objective and Criteria for Future Strategic Planning of Capital Cities[68]
- Our Cities, Our Future – a national urban policy for a productive, sustainable and liveable future[55]
- Towards Zero Road Safety Strategy 2008-2020[69]
- TravelSmart / Your Move[59]
- Western Australian Trails Strategy 2009-2015[70]

These strategies are also supported by peak industry cycling interest and road safety advocacy groups operating in WA, including Bicycling WA, the Bicycle Transport Alliance, Cycle Safe WA and West Cycle Inc.[71]

Additionally, in recognition of the growing importance of cycling safety, and that it is an issue which requires joint collaboration across government departments and agency stakeholders, the Premier of WA hosted a Cycling Safety Roundtable Workshop in March 2015, which brought together stakeholders and advocates to discuss the development of actions to improve cycling safety.[61] Attendees included Members of Parliament, the Road Safety Commission (formerly Office of Road Safety), the Department of Transport, the Department of Health, the Local Government Association, and bicycle advocacy groups. The workshop resulted in a number of initiatives to be considered for implementation, such as better education and awareness among cyclists and motor vehicle users to share the roads, changes to legislation to separate cyclists from motor vehicles, and improve road infrastructure to better accommodate cyclists.[61]

2.3 Cycling participation

2.3.1 International comparisons

Globally, the level of cycling participation is difficult to assess, as trends vary depending on the country, in addition to differing methods of measuring participation. An Organisation for Economic Co-operation and Development (OECD) report attempted to provide insight into this through a questionnaire administered to member countries.[1] Overall, the international level of cycling participation trend was generally stable over the period 2000-2010, noting that while some countries saw increases in participation (e.g. the United Kingdom and United States), rates were stable among high cycling participation countries (e.g. the Netherlands and Denmark), suggesting relative saturation.[1] Numerous Asian and medium-sized Northern-European cities (e.g. Agra, Jaipur, Amsterdam, Munich) observed cycling mode shares of over 10%, with some cities over 30% (e.g. Beijing, Copenhagen).[1, 72] These proportions were much higher than the proportion seen among large European and North American cities of less than 3% (e.g. London, Paris, New York, San Francisco).[1] However, as participation in cycling in Asian countries is strongly influenced by income levels, the accelerated economic growth of less-developed Asian countries in recent years is expected to see the uptake of motor vehicles, leading to a reduction in cycling as a mode of transportation.[1]

2.3.2 Australia

Levels of cycling participation are difficult to measure accurately in Australia, as there is no registration system for cyclists in Australia and therefore there are no reliable means of identifying the true number of the Australian population who cycle. Participation rates are often estimated based on national census data or extrapolation of household surveys.

According to the 2015 National Cycling Participation Survey, approximately four million Australians (around 17% of the population) ride a bicycle for recreational and transport purposes in a typical week.[73] Cycling has increased in popularity as a recreational activity in Australia in recent decades,[74, 75] with approximately 2.1 million people participating in 2010, representing a 45% increase compared to 2001.[74] According to the Australian Sports Commission’s Exercise Recreation and Sports Survey, cycling is the nation’s fourth most participated physical activity among Australians aged 15 years and over, after walking, aerobics/fitness and swimming. An estimated 475,000 Australians cycle, on average, at least three times per week.[74] Half of all Australian households have at least one working bicycle at home.[75]

As a form of transportation, 2% of Australians cycle to work or full-time study, with 50% of these people citing 'exercise and health' as the reason for this activity.[75] There was a 28.9% increase in the number of people who cycled to work as the sole mode of transport between 2001 and 2006,[76] and a 15.3% increase between 2006 and 2011.[77] These increases could, at least in part, be attributed to government strategies and dedicated health promotion campaigns such as the National Cycling Strategy 2005-2010.[78]

In contrast, the proportion of Australian children cycling to school has declined consistently over the last 20 years,[79] [80] with increased reliance on motor vehicles, longer travel distances and safety cited as the main reasons for the reduction in active transport among children.[81]

However, despite the overall increases in the number of cyclists, the 2015 National Cycling Participation Survey found that from 2011 to 2015, there had been a statistically significant overall decline in cycling participation rates across all States and Territories when population growth was considered, regardless of the purpose of cycling.[73]

2.3.3 Western Australia

Cycling participation rates in WA are among the highest of all Australian states and territories.[73] Based on the 2015 National Cycling Participation Survey,[82] 23% of Western Australians participated in cycling in a typical week in 2013, increasing from 405,000 cyclists in 2011 to 591,000 cyclists in 2013. Substantial growth in cycling uptake was seen in regional WA, with marginal growth in metropolitan areas. However when population rates were considered, cycling participation rates in WA did not demonstrate any statistically significant change from 2011 to 2015.[73] Of those Western Australians who cycled in the week prior to the survey, 80% cycled at least once for recreation, and 39% cycled for transport purposes. Stratified into regions, recreational cycling was more popular among regional cyclists compared to metropolitan cyclists (85% and 77% respectively), while cycling for transport was higher in metropolitan cyclists than regional cyclists (44% and 29% respectively). Approximately two in every three WA households has access to a bicycle.[82] However, it is important to note that the National Cycling Participation Survey is based on a household survey conducted via telephone, for participation in cycling occurring in the prior 12 months, and also requests the respondent to answer on behalf of other members of the household. These factors make the findings of the survey susceptible to selection and recall bias, and should be considered in the interpretation of results.

Results from the Monitoring the Perth Bicycle Network 2013 report, based on a survey conducted by the WA Department of Transport, indicated that use of the Perth Bicycle Network (PBN) in the WA metropolitan area is increasing.[83] The annual survey, conducted over a 10-day period, assessed the use of the PBN which consists of: local bicycle routes, mainly on suburban streets; Principal Shared Paths (PSPs), located along railway and freeway reserves; and recreational shared paths, located primarily along the river and coastal areas. The monitoring program consists of manual counting of cyclist usage of 109 locations in the Perth metropolitan area, including the central business district and suburban routes, taking place in the same week each year with recounts to validate data where findings were influenced by weather conditions.[83] This program reported a 29% increase in the use of the PBN in 2013 compared to 2012, a 38% increase on 2011, and a 430% increase on baseline figures reported in 1998.[83] Data from the WA Department of Transport from fixed electronic counters positioned at 11 primary PSPs on the PBN recorded a 35% increase in bicycle movements from 2012 to 2013,[84, 85] confirming the increases seen by the Monitoring the Perth Bicycle Network 2013 survey.

2.3.4 Barriers to cycling participation

Given the strong support provided by government authorities, and the health, environmental and economic advantages of cycling to individuals and society outlined above, the barriers to cycling participation need to be addressed to advance the prominence of cycling within Australian transport systems. It has been shown that increasing the number of cyclists can be an effective way of improving the safety of people who cycle, through a concept which has been referred to as ‘safety in numbers’ – the idea that an increase in cyclists leads to a decrease in cyclist injury and fatality.[86] This concept has been demonstrated through several international studies investigating differences in cycling participation rates and rate of injury.[72, 87] When cyclist numbers are increased, the behaviours of other road users, particularly motorists, also adapt to better accommodate other users who share the road.[86, 88] A study of child traffic injury in OECD countries found that countries could be separated into two categories: i) countries where there were high rates of cycling and safe cycling for children (such as the Netherlands, Germany and Norway), or ii) countries with low rates of cycling where child traffic fatality rates were high (such as New Zealand and the United Kingdom).[87] Australia falls into the latter of these categories.[75, 89]

The introduction of mandatory helmet laws for cyclists has sparked much research regarding the benefit of helmet use. Studies have found that cycling participation rates have decreased after the laws were introduced, suggesting that the helmets appear to have deterred cyclists from cycling in several Australian jurisdictions[90] including WA.[91] These decreases were consistent across studies using different methodologies, including cyclist surveys, focus groups and roadside counts.[90] Issues of comfort and appearance were the main factors cited as reasons for not wanting to wear a helmet.[92, 93]

The issue of inconvenience was often cited as a significant barrier to the uptake of cycling among cyclists wishing to cycle as a form of transportation.[93] In particular, the need to change clothing after cycling at work or school, difficulties in carrying items (including a change of clothes), and having secure parking, have been consistently identified in surveys and focus group studies as areas which need to be addressed.[45, 93] The enhancement of end-of-trip facilities (such as secure pedal cycle parking and lockers) would encourage and assist cyclists use pedal cycles to commute to work or school.[94]

It is crucial that interventions aimed at improving cycling participation rates also address not only concerns relating to the physical environment, but also potential future cyclists' perceptions and attitudes toward cycling. Research suggests that the perception of safety is an important factor in attracting new cyclists to the use of the bicycle in place of a motor vehicle.[8] In Australia, the perceived danger in cycling as an activity has contributed to the limited uptake of cycling, demonstrated through increased levels of participation in areas where cycling is perceived to be a safe activity.[95] Non-cyclists, or cyclists with less experience, have greater safety concerns associated with cycling than regular cyclists.[96, 97] Sharing the road with other road users, particularly motor vehicles drivers, is primarily cited in qualitative studies as the most dangerous aspect of cycling, due to concerns regarding traffic volume, passing distance, and high speeds of other vehicles,[93, 94, 97-99] though consideration must be given to potential selection and response bias in these studies. Perceptions of driver aggression,[45, 96, 100] fuelled by road rage incidents between motorists and cyclists publicised through the media,[101-103] adds to apparent risks of cycling. On the other hand, cyclist-perceived driver aggression may be associated with driver-perceived failure of cyclists to adhere to road rules.[96, 104]

A bicycle network which separates cyclists from other road users may encourage novice riders who are likely to be less confident to take up regular cycling,[45, 98] however it is important to consider that motor vehicles are not the only danger to cyclists, the risks to other road users such as pedestrians should not be ignored.[105] While the construction of cycle-specific infrastructure such as bicycle lanes and shared paths can be costly, the lowering of speed limits and introduction of traffic calming measures (such as speed humps) have the potential to make the road environment safe for all road users, without significant investment that will benefit only cyclists.[72, 106] 'Bicycle boulevards' were introduced in Perth in 2015 to test this theory – selected roads connecting schools, shopping centres and train stations have a road speed limit of 30 kilometres per hour and give priority to pedal cycles over motor vehicles;[107] however the effectiveness of such measures are yet to be determined.

It is unclear how accurately these perceived risks of cycling associate with actual risk. Without a comprehensive evaluation of cycling injury and fatality, and identification of actual rates of injury, perceptions of cycling as a dangerous activity may be unfounded.

2.4 Cycling injury in Australia and Western Australia

Injury is a significant cause of preventable death and disability and also presents a sizeable health care cost; in 2004-05, injuries cost the Australian health care system $3.4 billion.[108] Injury prevention and control was declared a National Health Priority Area by Australian Health Ministers in 1996[109] and the National Injury Prevention and Safety Promotion Plan: 2004-2014 was developed to reduce levels of injury in Australia. Safe recreational and transportation systems were identified in this plan as a key area where injuries across all age groups could be reduced.[67]

While the increase in the uptake of cycling is generally seen to be a positive outcome, the push to increase cycling will inevitably be accompanied by an increased number of cycling accidents and subsequent injury. There is a higher risk of injury among cyclists due to extrinsic factors compared to any other road user groups.[110] With improvements in bicycle technology, modern pedal cycles have the capacity to travel at considerably high speeds, and as cyclists are relatively unprotected on the road, they are at a higher level of injury risk when sharing the road with other vehicles.[110] It is estimated that the risk of death while riding a bicycle is 12-times higher than when driving a car.[111]

2.4.1 International comparisons

Similar to cycling participation, cycling injury levels vary markedly across different countries, making comparisons difficult. High level reviews conducted internationally have shown that countries in the World Health Organisation (WHO)-defined Western Pacific Region, which includes Australia and New Zealand, have the highest proportion of road traffic fatalities attributable to bicyclists, compared to countries in the European, American and South-East Asian Regions.[112]

There are substantially lower serious cycling injury and fatality rates in European counties such as the Netherlands and Denmark, compared to other Western countries such as the United States. This has been attributed to better cycling education, enhanced infrastructure, and integrated road traffic systems which encourage cycling over motor vehicle use.[72, 87]

2.4.2 Australia

Transport injuries account for the third-highest number of all injuries in Australia, and pedal cycles are the third leading cause of all transport injuries.[109] Cyclists account for one in 40 Australian traffic crash fatalities.[113] In the 10 years between 2005 and 2014, traffic-related fatalities for cyclists in Australia ranged between 28 and 50 deaths per year, with an average of 38 deaths per year.[114] Car drivers, car passengers, pedestrians and motorcyclists all reported average annual decreases in fatality of 4.4%, 5.2%, 4.3% and 2.0% respectively; pedal cyclists were the only road user group to have an average annual increase in fatalities (1.4%).[114] In terms of hospitalised injury, one in six Australian hospital admission for land transport accidents were for cyclists.[113] Pedal cyclists had the third highest rate of hospitalised injury nationally, after car drivers and motorcyclists, in 2008-09.[115]

2.4.3 Western Australia

For the period 2010-2014, cyclists made up 2.8% of all WA traffic fatalities, a 1.4% increase on the previous five year period (2005-2009).[113] In the WA Road Safety Commission's (RSC) annual *Reported Road Crashes in Western Australia (RRCWA)* publications, for the period 2008-2012, police traffic crash records showed that pedal cyclists accounted for the fourth highest number of hospitalised serious injuries among all WA road users after car drivers, car passengers and motorcyclists. However in 2013, the number of injured cyclists surpassed the number of injured car passengers, and ranked as the third most common injured road user group.[4] In that year, bicyclists made up 5.5% of all persons killed or seriously injured in WA traffic crashes, a 4.6% increase on 2012.[4] However, these statistics were based on police-reported traffic crash data, and do not include cyclists who were involved in crashes which were not reported to police.

According to RRCWA information sourced from hospital admission data, the number of injured cyclists (n=744) increased by 13.2% in 2013, compared to 2012, making this road user group the third most common road user group to sustain injuries requiring admission to hospital after motor vehicle drivers and motorcyclists.[4] However, it is likely that this figure underrepresents the true number of injured cyclists, as these figures did not consider where a person may have had multiple crash incidents within 12 months, and also did not include fatalities. It was not possible to combine the hospital inpatient data with the police-reported data to determine an overall cycling incidence for WA, as duplication across the data sources was likely (i.e., where a person was in a police-reported crash and also was admitted to hospital), which would have resulted in the overestimation of true cycling injury figures.

In terms of the cost of cycling injury, WA studies carried out in the late 1990s suggested that 68% of all cycling-related hospital admissions were for head injury of moderate severity.[12] Then, the cost of a moderate head injury was estimated at $45,500,[116] equating to approximately $21 million per year across the State. However, this figure only included head injuries of moderate severity, and did not take into account severe injuries which are likely to have a greater cost, or injuries to other parts of the body and minor injuries which were less likely to be reported.

2.5 Measurement of cycling injury

Cycling injury has been researched from several different perspectives – including road safety, injury prevention, road design and infrastructure, and road user behaviours. The approach taken influences study design, and as a result, reported characteristics of injured cyclists can differ depending on the source of the study population and severity measures used.

2.5.1 Data sources

Research studies examining cycling injury are based on either administratively or non-administratively collected information.

Cycling injury research based on non-administratively collected information comprise studies which utilise data collection methods such as questionnaires, focus groups and interviews. These studies are based on cyclists recruited specifically for the study, through means such as calling for volunteers,[45, 117] recruitment via cycling events[118] or approaching cyclists who present to EDs and hospitals.[119, 120] The targeted selection of the study cohort means that selection bias is often a concern, particularly where participants volunteer to participate, especially in areas with a strong or large number of cycling advocacy groups.[117] Such studies also often require cyclists to describe their past experiences,[118] and accordingly recall bias must also be considered in the interpretation of results, in addition to reporting bias where a cyclist may provide responses in order to comply with community expectations (e.g. report the use of helmets where they were in fact not worn, in areas where helmet legislation applies).

Administratively collected data refer to records which are collected as part of routine operations of an organisation (e.g. police crash records or hospital records). Administrative data are often comprehensive, cover a large proportion of the population, and can be collected over an extended period of time.[121] However as these data are collected for a specific operational purpose, administrative data may not always be adequate for research purposes. Additionally, data definitions may change over time due to changing administrative needs.

A review of research literature shows that two administrative data sources are commonly used as the source of cycling injury study populations: (i) police crash records, which report the circumstances relating to the crash and the vehicles involved, and (ii) hospital records, which report the injuries sustained and the medical treatment received. There are significant differences between the hospital and police records, which have implications for cycling injury research findings, due to the separate motives and methods driving the data collected in each administrative data source, and therefore the different nature of the data collected. Both of these reasons affect the interpretation of results when used in academic research, as comparisons between studies can be challenging when the source of data are not directly comparable.

In Australia, police traffic records are traditionally used to measure road safety performance, and thus guide government policy.[4] However as traffic crash data are heavily dominated by crashes involving motor vehicles, police traffic data sources have consistently been shown to underreport road crashes for non-motor vehicle road user groups.[5, 122-124] The level of underreporting is subject to variation depending on different modes of transport. A meta-analysis of 49 studies on road crash reporting in 13 countries, recognizing there are differing reporting requirements across nations, [125] showed that levels of formal reporting were highest for accidents involving motor vehicles, and lowest for cycling accidents, especially for single-bicycle accidents. Accidents involving cyclists are often not reported as they are deemed to be minor and are associated with lower vehicle repair/replacement costs.[122, 126] The injuries sustained can also be less severe, and medical treatment may not be sought.[124, 127] WA's Towards Zero Road Safety Strategy 2008-2020 is based on police-reported data, and it is concerning to note that a state-wide strategy aimed to reduce road injury, including those among cyclists, has been developed based on information which may not sufficiently capture the full extent of the issue.

For WA, the deficiencies of using police data to study cycling injury were described by Gavin,[11] who demonstrated that the number of cases between police reported and hospitalised cases could differ by more than 8,000 cases over a 14-year period. Similarly, Piggot[6] showed that when the two data sources were linked, only 1.1% of cases were recorded in both police and hospital admissions data. However, both of these studies did not take into account the number of multiple admissions relating to the same accident event, such as those arising from hospital transfers – which is likely to have overstated the number of hospital admissions and therefore biases the comparisons made between the two data sources.

In addition to low ascertainment of cycling-related crashes, the underreporting of cycling injury in police records is further exacerbated by the lack of reliable information pertaining to cyclist injuries. Road crash data focus on characteristics relating to the crash event, such as vehicle characteristics (e.g. vehicle type, vehicle speed and direction of travel) and road characteristics (e.g. road speed, traffic control measures, road type).[128] Information relating to injury resulting from a crash are secondary factors, which also often manifest after the crash event, and therefore the completeness and reliability of these items in police data collections are uncertain. Studies have shown that cyclist crashes requiring hospital treatment are substantially underreported to police, including research from WA,[5] Australia[124, 129, 130] and internationally.[131-133] Langley et al[122] found that only 22% of cyclists admitted to hospitals for an injury had been reported in a police report. Previous WA research has revealed that cyclists account for 1% of all road traffic crashes, compared to 14% of hospitalised road users, in inpatient hospital data.[12] Therefore studies which have used police records as a study population source are limited in detail regarding injuries sustained by cyclists.

Conversely, while the use of hospitalisation records has better ascertainment rates of cycling injury, the nature of administratively collected hospitalisation data focusses on factors relating to the injury (e.g. type and anatomical location of injury) and the associated hospitalisation event (e.g. length of hospital stay, type of care, procedures performed), with little detail on the crash circumstances.[134, 135] As such, studies using hospital records as a source of cycling injury have been limited regarding details of the cycling accident resulting in injury.[105, 136-138] Additionally, as admission records focus on the health of the injured rather than the crash, it can be difficult to accurately determine the number of crashes resulting in injury from hospital data, as a patient can have multiple admission records (e.g. hospital transfers, planned and unplanned readmissions) resulting from injuries arising from the same crash event.[139]

Therefore given the limitations of the crash and hospital admission data, it would be ideal to combine the two sources to gather as much information as possible relating to the injured person and the events causing the injury.[135, 138] Through the recognition of the value of linked administrative data sources and advances in technology, the use of linked data studies have increased rapidly, particularly in Australia where data linkage capabilities have grown considerably in recent years.[140] The point where primary prevention measures can be best introduced to facilitate the largest reduction of cycling injury would be at the time of the accident, and thus it is important to take both accident and injury factors into account when planning interventions. To date, research studies utilising data linkage to investigate road injury trends have not been specific to cycling injury;[135, 141] linked data studies examining cycling injury have either focused on linkage rates between data sources[124, 130, 131] or specific aspects of injury, such as head injury[142] and paediatric injury.[143] No previous study has used a linked dataset of police and hospital admissions to quantify cycling injury at a population level.

2.5.2 Injury severity measures

There are several injury severity measures used in road injury research literature, each derived using different methods. Australian studies using police crash records commonly use the injury severity measure used by the police – where an injury is determined to be 'serious' if the casualty was transported to hospital.[144] However, police records have been shown to overstate injury severity[145] through the assumption that transportation to hospital results in hospital admission, therefore the validity of this measure has been questioned for use in road injury studies.[5, 146]

Injury severity scales are also often used in cycling injury studies using hospital-based data sources, including the Abbreviated Injury Scale (AIS), Injury Severity Score (ISS), New Injury Severity Score (NISS) and the International Classification of Diseases Injury Severity Score (ICISS).[147]

The AIS ranks injury using an anatomical scoring system which represents an injury's threat to life based on the type, location and severity of injury.[148] However, the AIS is based on single injuries, and the ISS and NISS can be used to summarise AIS scores to determine the severity of multiple injury.[149] The use of the AIS, ISS and NISS is limited in road injury studies, and in particular cycling injuries. The AIS data are intensive to collect, as they can only be coded by trained staff who are accredited through the Association for the Advancement of Automotive Medicine codes.[148] In WA, AIS data are only collected in state trauma registries, and the Insurance Commission of WA – therefore data are limited to only trauma registry patients and injured claimants, and would only represent a subset of the injured cyclist population.[13, 150] The ISS can only consider, at most, a patient's injuries in the three most severely injured regions of the body; to overcome limitations of the ISS where only one injury in each body region is recorded, the NISS uses the three most severe injuries in its calculation, regardless of body region. [151] However, both severity scores were not designed to be a comprehensive summary of injuries in all body regions.[152, 153]

ICISS uses International Classification of Disease (ICD) codes recorded in a patient's hospital record to derive a 'threat-to-life' indicator, which estimates the probability of a patient surviving a given set of injuries based on ICD codes for their hospital admission.[153] The ICISS has been shown to outperform other injury severity measures in predicting mortality, and other factors such as duration of hospital stay and resources.[153-156] The ICISS methodology has also been validated in other countries[157, 158], and a number of studies have found the ICISS to be the better indicator of injury when using Australian and New Zealand hospitalisation data compared to the AIS.[147, 159] As the ICISS is comparatively easier to use than ISS and NISS – due to availability of ICD coded data already collected by hospitals, the lack of dependence of AIS-specifically trained staff, or reliance on AIS lexicon – it is expected that the use of ICISS will continue to be adopted more widely in injury research.[153, 158] It has been utilised in road injury studies, including cycling injury studies[13, 105, 143, 160] and its use with linked data has also been explored in the Australian context.[161]

2.6 Characteristics of cycling injury

Injury can be prevented by reducing the event causing the injury from occurring; or where the event has already occurred, factors related to the person, vehicle or environment can reduce the impact and severity of the injury.[162] One of the main goals of epidemiology is to identify sub-groups of the population who are at-risk of disease; or in this case, injury. By doing so, characteristics which put cyclists at high-risk of injury can be elucidated, and by modifying such risk factors, rates of injury may be reduced. Additionally, prevention strategies can be specifically targeted to reduce the risk of injury for at-risk populations. Thus, the first step in the prevention of cycling injury in WA is to understand the problem – who is at risk of cycling injury, and what characteristics place a cyclist at risk of sustaining a serious or fatal injury? To achieve a greater understanding, empirical evidence is needed.

Characteristics of cycling injury can be stratified into three areas: (i) cyclist characteristics – factors associated with the injured individual, (ii) injury characteristics – characteristics pertaining to the injuries sustained by the cyclist, and (iii) accident characteristics – factors related to the circumstances surrounding the accident event.

2.6.1 Cyclist characteristics

Injured cyclists are predominantly male, and this finding is consistently replicated across multiple studies of differing study design.[11, 136, 163-166] Studies sourcing study populations from hospital records reported a greater proportion of cycling injury among children than adults, compared with police-based study sources which report a higher proportion of injured adult cyclists.[6, 11, 136] This difference reflects the overrepresentation of on-road cycling accidents reported in police data; population-based studies examining across both police and hospital data in Australia confirm that children and adolescents comprise a greater proportion of cycling injuries overall,[142, 167] though cycling injury in older age groups has been increasing.[164] Road trauma is one of the most common causes of injury in children and adolescents,[143] and past studies have examined injury risk factors specific to young cyclists and the environments and circumstances in which they cycle.[143, 167-169]

2.6.2 Injury characteristics

2.6.2.1 Type of injury

Fractures and open wound injuries are the most common form of injury sustained by cyclists, findings which were replicated across multiple countries including Australia.[118, 127, 165] [12]

Handlebar injuries have been associated with injuries such as intestinal, liver, pancreatic and splenic injuries and abdominal wall rupture,[170] and thus bicycle accidents are a common cause of abdominal injury, particularly in children.[171, 172] An increase in these injuries has been observed in children presenting to EDs in Australia[173] and internationally[174], owing to an increase in off-road cycling activities such as BMX and mountain bike riding. Findings in Austria by Nehoda[175] regarding the use of bar ends, grip attachments to assist in cycling comfort and hill climbing, and their strong association with liver injuries led to the modification of the shape and material of bar ends used in that country. This resulted in the elimination of liver injuries observed in the hospital used in the study in the three years following the implementation of the recommendation. However, the generalisability of the findings from this study are not clear, as the small size of the study population and observed liver injuries should be noted. Therefore the effectiveness of this recommendation internationally is not known.

Upper extremity injuries are the most common body region injured for cyclists of all ages, with head injuries and lower extremity injuries also common.[137, 142] These findings were confirmed to apply to the WA population in a study of patients presenting to an emergency department[119] and a review of inpatient hospital data between 1987 and 2000.[12]

Of all injury prevention strategies, the effectiveness of helmets in reducing head injuries has been studied the most extensively, prompted by the introduction of mandatory helmet legislation in several countries including Australia. Australian studies found that mandatory bicycle helmet legislation introduced in the early 1990s had a positive effect in reducing the number of head injuries,[176, 177] as have international studies.[136] The risk of head injury associated with helmet use was examined in a Cochrane Review of five studies, which concluded that the use of helmets reduced the risk of head and brain injury by 63% to 88%.[178] This review also found that helmets were equally as effective in crashes that involved only cyclists compared to cycling crashes also involving motor vehicles.[178] Additionally, a meta-analysis of 43 studies conducted in 2016 assessing the effectiveness of helmet use in a crash or fall substantiated these findings, concluding that helmet use was associated with reduced odds of facial injury, and serious and fatal head injury.[179] The role of helmet use in reducing the severity of head injuries has also been examined in linked data studies[142] which found that the use of helmets was associated with reduced risk of head injury in collisions where motor vehicles were involved, as such collisions have been demonstrated to result in greater odds of severe injury.[180]

However a decline in the number of cyclists was observed in the years after mandatory helmet legislation was enacted,[181 182] with studies suggesting that the laws had deterred cycling participation,[90] diminishing the apparent overall public health benefits. Studies have attempted to balance the benefit of the reduced number of head injuries against the harm of reduced physical activity to determine if helmet laws have a net societal health benefit.[183, 184] The findings from these studies concluded that further work on behavioural factors was needed, as the impact of helmets can vary depending on perceived levels of cycling safety. Additionally, there is evidence to suggest that the use of helmets encourages risk taking behaviour such as riding at higher speeds[90, 185] while also disproportionally discouraging slower-speed, safer cyclists – thereby increasing the average overall risk per cyclist.[186] The lack of accurate cycling exposure data is well documented,[89] without which true rates of injury cannot be determined, contributing to conflicting evidence as to whether helmet laws have improved overall public health and cycling safety.

2.6.2.2 Injury severity

Using ICISS injury severity reporting methods, Chapman[187] reported that 22% of cyclists in WA suffered serious injury across the period 1988 to 2006, the fourth highest incidence of serious injury of all road user groups, which was consistent with national figures.[115] The risk of serious injury was increased when cyclists were involved in collisions with a motor vehicle[105] and this finding was also seen in studies employing other injury severity measures such as AIS[188], ISS[136] and hospital attendance.[117, 189] A study by Meuleners[119] found that most cycling injuries sustained by patients presenting to a Western Australian ED were of minor or moderate severity, as classified by the AIS. However, as this study was conducted on patients who provided consent to participate, and it is possible that more severely injured patients may have been less likely to be able to provide consent, introducing selection bias. Additionally, recall bias may also have influenced the findings, particularly where children were injured and parents were not witnesses to the accident.

International studies based on police crash data employing multivariate analysis methods have shown that older age, lack of helmet use, and cycling on higher speed-zoned roads were significantly associated with severe cycling injury when measured by ISS[136]. A multivariate study conducted in New South Wales, Australia demonstrated similar findings with outcomes based on hospital attendance.[144]

An Australian study by Mitchell[143] which examined the relationship between body region and injury severity using ICISS methodology, found that the head and neck were the most common body regions involved in serious injury, and moderate and minor injuries were predominately the result of lower leg and upper leg injuries.[143] However, this study was limited to children and therefore findings were not generalizable to the entire Australian population.

2.6.3 Accident characteristics

Research based on police reports found that most cycling accidents resulting in injury involved another vehicle, most often motor vehicles.[144] This is in contrast to findings based on hospital records, where non-motor vehicle collisions were the most common form of collision reported.[12]

Studies using Australian and international hospital sources report a higher proportion of off-road accidents and non-collision accidents, compared to police sources which report a higher proportion of on-road accidents and accidents involving motor vehicles.[11, 12, 118, 119, 137, 188] Off-road accidents include those from mountain bike riding, which has seen an increase internationally.[190] Due to the adventurous nature of the sport, with unpredictable terrain and high relative speed, mountain bike riding has been associated with high severity of injuries,[174] and a higher risk of accidents than road cycling.[191]

Police reported information shows that right-angle or side-swipe (same direction) collisions were the most common types of cycling crashes reported in Australia.[12, 144] Early morning (6am to 9am) and afternoon (3pm-6pm) are the peak times for cycling accidents to occur, often in daylight conditions.[12, 120, 144, 166] Most cycling accidents in Australia occurred in urban areas,[144] consistent with WA findings where most accidents occurred most often in metropolitan areas.[11, 192]

These findings are confirmed in naturalistic studies conducted in Australia, which have shown that most injuries involve a cyclist and motor vehicle driver, and side-swipe collisions were the most frequent form of collision.[193] Incidents such as drivers turning left across cyclists' paths and collisions with opened vehicle doors were common, and events most often occurred at an intersection.[194]

Studies on the accessibility to health facilities following a crash appear to be limited, which would be assumed to influence the outcome of injury. Measures based on the time taken to seek medical attention following the crash, or the distance from the crash site to the nearest or treating facility were not evident from literature reviews.

2.7 Chapter summary

This chapter has presented the case for encouraging cycling participation, by detailing the health and economic benefits of cycling at an individual and community level, and also to the environment. It outlined the plethora of strategies, initiatives and investments made to encourage cycling, demonstrating support for increased rates of cycling at all levels in Australia. This chapter detailed cycling participation figures, and barriers to participation were described.

The demonstrated importance of cycling participation fuels the need to decrease the incidence of cycling injury to make cycling a safe activity for all. The perception of safety of cycling as an activity was briefly explored, as this was found to be a significant factor in influencing cycling uptake. However, the difference between perceived and actual risk of injury is difficult to determine, and demonstrates the need for a better understanding of cycling injury.

Reported cycling injury rates, and sources of this information were examined, with particular focus on those for WA. Findings from this literature review indicate that there are a significant number of cycling injuries in WA which are not reported to police. Given that police-reported statistics which are commonly referenced by authorities and policy makers are underestimating the real number of injured cyclists in WA, there is significant concern that a substantial proportion of those affected by cycling injury have not been considered in state-wide strategies to reduce cycling injury. Additionally, it means that efforts required to realistically achieve strategic targets will be greater than expected. However, it is not to say that studies using hospital admission data are not flawed; most studies reviewed did not consider that a single cycling accident may result in multiple planned or unplanned hospitalisations, potentially overstating the true number of hospital admissions. Linked data studies in this field have demonstrated the potential for data linkage to be utilised across different data sources to address cycling injury reporting issues.

This chapter also reviewed the characteristics of cycling injury as described in the research literature. Generally, international findings for characteristics relating to the cyclists, injuries they sustained, and accident characteristics were similar to those found in Australian studies. However, as the ascertainment of injured cyclists relative to the general population is low, the size of populations studied were called into question, particularly those studying specific forms of cycling injury. Additionally, due to the challenges of capturing a sufficient number of cyclists for study, the research design of some studies used targeted cohorts which often introduced bias into the study methodology.

It was found that research methods vary widely in this research area, and thus differing aspects of research methodology in the field of cycling injury was examined. Given agreement across multiple studies endorsing the use of hospital-based information for the study of cycling injury, and the questionable validity of police-based injury severity measures, the review of the literature supported the use of injury severity scores over hospital attendance status. Thus, common measures of injury severity were examined in this chapter, and as the accessibility of injury severity measures of different data sources varies, the ICISS was demonstrated to be the most comprehensive and readily-available measure for hospital-based information.

In summary, in order for the WA population to increase cycling participation and realise the various benefits cycling has to offer to individuals and the wider community, it is essential to make cycling a safe activity for all who participate. To do this, it is necessary to examine as many aspects as possible which may influence the safety of all cyclists, not only a select proportion. Therefore, in line with the Australian National Road Safety Strategy 2011-2010 to have improve empirical data to assist in reducing road trauma, the full extent of cycling injury needs to first be properly determined using appropriate sources to understand the impact this issue has on the wider community. Then, factors pertaining the cyclists themselves, and those relating to the accidents resulting in cycling injuries can be examined, to determine factors which can be influenced to improve cycling safety. For such a thorough analysis to occur, a study ideally needs to examine a study cohort which adequately and reliably captures cycling injury, is less prone to bias, and is representative of the general population. Some studies in this literature review have demonstrated the strengths of using population-level data linkage to study specific aspects of cycling injury, however no study to date has used this methodology complete a comprehensively descriptive review of cycling injury.

Chapter 3 Methods

3.1 Chapter overview

This chapter will describe the methodology used in this study, which aims to address shortfalls identified in other studies in this field, as described in the previous chapter. First, the broad study aims and study design will be described. To provide context to the population of interest, the study setting will outline the geographic and demographic characteristics of WA.

As the use of linked data is key to this study, data linkage methods are described, including the role of the WA Data Linkage Branch (WADLB). Data sources utilised by this study, and the information available, are described. Key aspects of working with linked data are outlined, including data processing, cleaning and manipulation. Approvals obtained for this project are also detailed.

The methodological processes involved in examining each study aim will be described, including specific analytical methods and statistical analysis.

3.2 Study aims

The study population examined in this study was stratified into sub-cohorts:

1. Overall Cohort – all severe or fatally injured cyclists, i.e., the study population
2. Sub-Cohort 1 – cyclists who were severe or fatally injured in accidents which were not reported to police, i.e., did not have a linked police crash record.
3. Sub-Cohort 2 – cyclists who were severe or fatally injured in accidents which were reported to police, i.e., had a linked police crash record.

The study population used to investigate each study aim and objective is outlined below:

Aim 1. **To quantify levels of severe and fatal cycling injury in WA, based on hospital and death data: 1995-2010 (Overall Cohort)**

Aim 2. **To characterise severe and fatal cycling injury in WA in terms of sociodemographic, injury type, accident type and geo-spatial factors: 1995-2010**

Objective 2a. *To characterise cyclist, injury and accident related factors in severe and fatal cycling injury (Overall Cohort)*

Objective 2b. *To characterise differences in severe and fatal cycling injury between cases with and without police-reported crash records (Sub-Cohort 1 versus Sub-Cohort 2)*

Objective 2c. *To describe accident and geo-spatial characteristics of severe and fatal cycling injury, based on police-reported crash records (Sub-Cohort 2)*

Aim 3. **To determine risk factors for being killed or seriously injured (KSI) in cycling accidents in WA: 1995-2010**

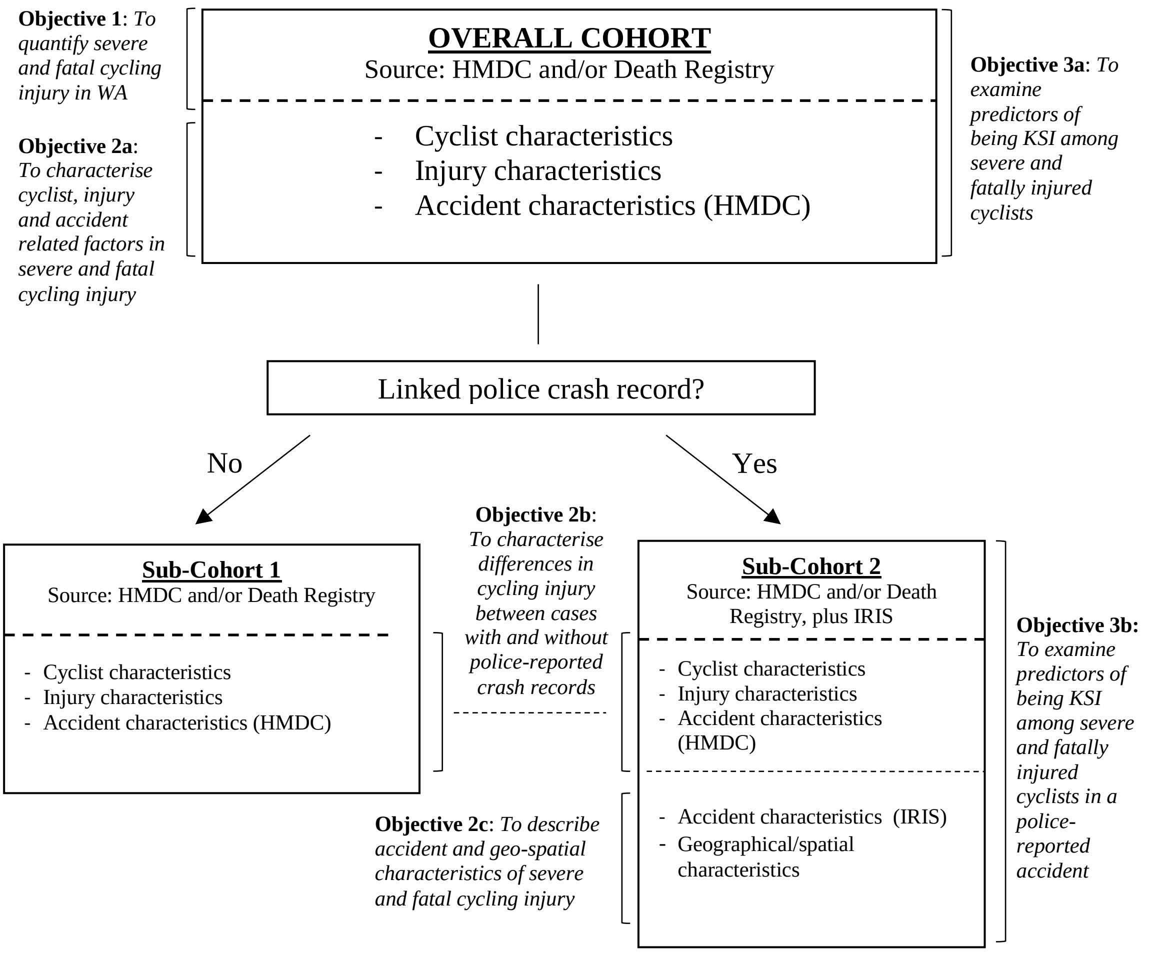
Objective 3a. *To examine predictors of being KSI among severe and fatally injured cyclists (Overall Cohort)*

Objective 3b. *To examine predictors of being KSI among severe and fatally injured cyclists in a police-reported accident (Sub-Cohort 2)*

The relationship between the study cohorts and the study aims and objectives are illustrated below in Figure 1.

Figure 1: Overview of study cohort and groups

Aim 1: To examine levels of severe and fatal cycling injury in WA: 1995-2010
Aim 2: To characterise severe and fatal cycling injury in WA: 1995-2010
Aim 3: To determine risk factors for being killed or seriously injured (KSI) in cycling accidents in WA: 1995-2010



3.3 Study population

The study population consisted of all people who were discharged from hospital for an inpatient admission and/or died as a result of an injury from a cycling accident in WA between January 1995 and December 2010.

3.4 Study design

This study was a retrospective, longitudinal descriptive evaluation of a cohort, utilising linked population-level data to examine cycling injury in WA. Linked administrative inpatient admission, road crash and death data were used to address criticisms of previous studies in this field – that being the underreporting of cycling injury among police crash records,[5, 11] the lack of crash circumstance information in hospital-reported data[6, 105] and equally the lack of reliable injury data in police data.[132] Use of linked data also has advantages for reducing selection and recall bias compared with studies using questionnaire/interview methods.[117, 118, 168, 192, 195]

The study period of 1995 to 2010 was chosen to capitalise on the longitudinal nature of linked data, as this 16-year period was the maximum time period common to all data sources.

3.5 Study setting

3.5.1 Characteristics of Western Australia

WA is the largest Australian state in terms of geographical area, with its land mass covering approximately 2.5 million square kilometres.[196] Although this equates to 33% of Australia's total land mass, WA is home to approximately 11% of the total Australian population, with an estimated resident population of approximately 2.5 million people.[196] Although large in size, more than three quarters of WA's population (78%) reside in the capital city of Perth,[196] with the Perth metropolitan region covering approximately 6,400 square kilometres.[196] WA is serviced by 91 public hospitals and 62 private hospitals,[197] and the State's six public teaching hospitals are all located in Perth.

Geographically, Perth is bordered by the Indian Ocean to the West and inland desert to the East. Perth is one of the most isolated capital cities in the world,[75] which has contributed towards Perth's low rate of permanent out-of-state migration.[198] The WA population has been shown to be highly representative of Australian jurisdictional averages for socio-demographic and health indicators.[198] Coupled with a well-established record linkage system, these characteristics make WA an ideal setting for population based epidemiological studies.[121]

3.6 Data Linkage

Data linkage is a technique which creates links between data sources for information that relates to the same person, place or event.[199] Analysis of linked data is being increasingly used in epidemiological studies as it provides an efficient and cost-effective means of obtaining longitudinal population-level data which would be prohibitively costly to collect otherwise.[200] In addition, when population-level administrative data are used, data linkage also minimises issues of selection, recall and reporting bias, as well as loss to follow-up.[201] The use of whole-population data maximises statistical power, and allows effective evaluation of even marginal changes in policy, facilitating research which is directly applicable to the whole population.[201] The linkage of multiple health datasets creates a rich resource for understanding the epidemiology of health conditions, creating a more complete understanding of underlying causes.

3.6.1 WA Data Linkage System

The data linkage capability in Australia is one of the largest in the world, with several centres constructed to facilitate the linkage of multiple, large, population-based, administrative datasets.[140] Among the centres in Australia, the WA Data Linkage System (WADLS) is the most established data linkage system, commencing operation in 1995.[199] It is a complex system for the creation, storage, update and retrieval of links between health and welfare-related data.[199] It creates a linkage key between over 40 population-based administrative and research data collections. As some of the datasets go back as far as the 1960s, it enables longitudinal study of the WA population for major diseases and conditions and utilisation of health services.[201] The linked data have also added value to existing State administrative data collections, through improving data quality and enabling data validations.

The WADLS contains records from 'core' datasets comprising health data managed by the WA Department of Health (WA DOH), and birth and death registrations (Figure 2). The core linkages are updated regularly, most on a monthly basis. Other additional data collections (both from government and non-government agencies) are also linked, however, these links may not be updated as regularly as the core datasets.[199] The WADLS is maintained by the WADLB, which is funded through the WA DOH, state agencies, the Australian Government and research grants.[199]

Figure 2: WA Data Linkage System: data collections[199]

FAMILY CONNECTIONS

Births, Deaths & Marriages

WA HEALTH

Home & Community Care

Aged Care Assessment Program

WA Notifiable & Infectious Diseases

Monitoring of Drugs and Dependence

Drug & Alcohol Office

State Trauma Registry

WA Registry of Developmental Anomalies

Health & Wellbeing Surveillance

GEOCODING

SEIFA & ARIA for 1996, 2011, 2006 Census

CORE DATASETS

HOSPITAL MORBIDITY DATA COLLECTION (since 1970)

MENTAL HEALTH INFORMATION SYSTEM (since 1966)

EMERGENCY DEPARTMENT DATA COLLECTION (since 2002)

WA CANCER REGISTRY (since 1982)

MIDWIVES NOTIFICATIONS (since 1980)

BIRTH REGISTRATIONS (since 1974)

DEATH REGISTRATIONS (since 1969)

WA GOVERNMENT

Department of Child Protection

Department of Education

Disability Services Commission

Department of Housing

Department of the Attorney General

School Curriculum and Standards Authority

OTHER ORGANISATIONS

Silver Chain Nursing Association

Insurance Commission of WA

Main Roads WA

St John Ambulance

IDEA Database

BreastScreen WA

Playgroups WA

3.6.2 Data linkage processes

As a unique person identifier across all state data collections does not exist in WA, information is linked by the WADLB using probabilistic matching methods. This involves creating linkages between records by comparing personal information and calculating the likelihood the records belong to the same person, place or event. Empirical weights are assigned based on the likelihood of being a correct match, and thresholds are set to determine probable versus improbable matches. Where the likelihood is unclear, the link is manually reviewed by a linkage officer.[199]

The data linkage methods employed by the WADLB enable the protection of privacy of Western Australians through a best-practice protocol employed by data linkage centres in Australia.[202] There are three parts to this principle:

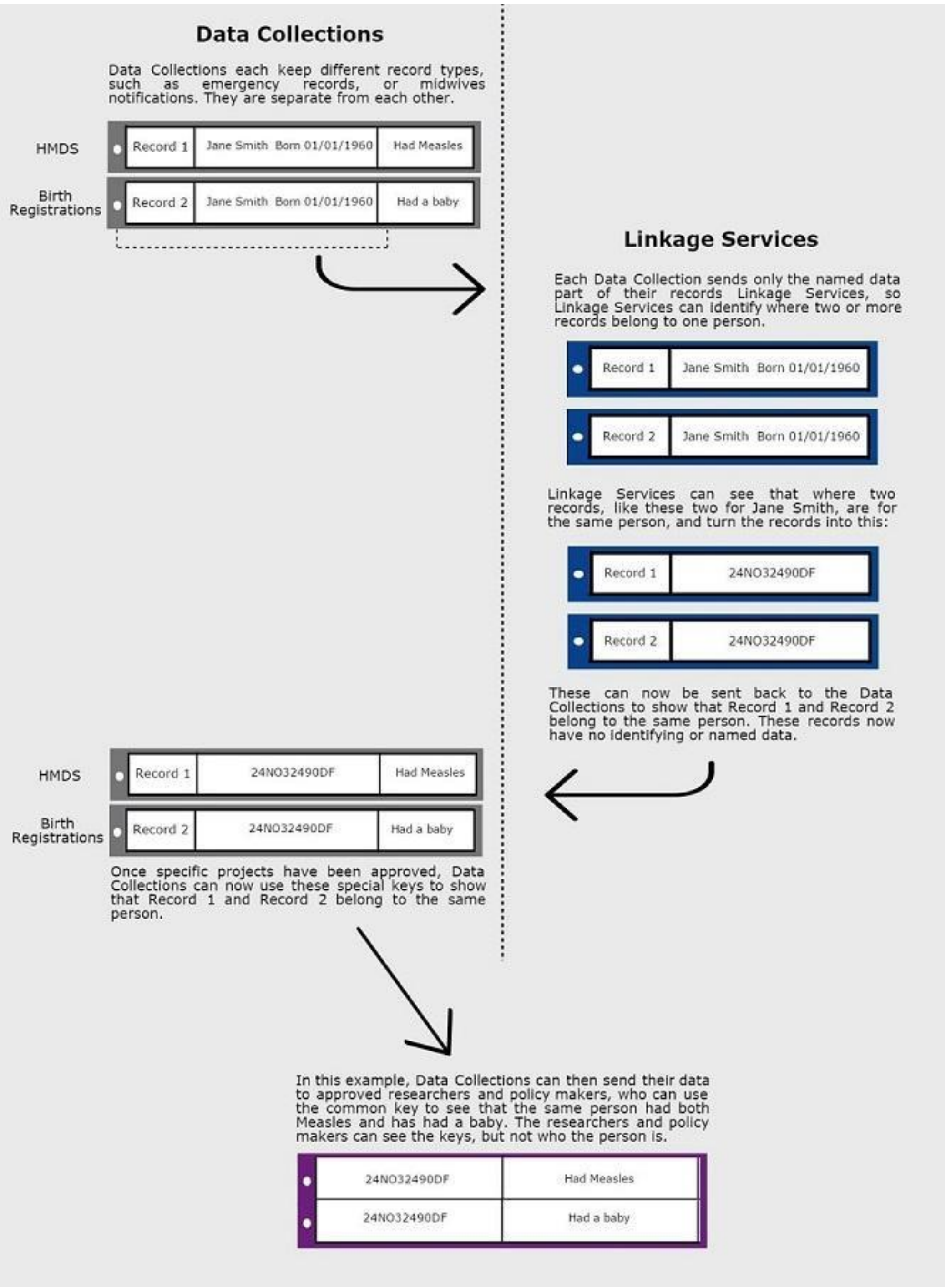
1. Data linkage officers use personal identifying information (e.g. first name, surname, date of birth, residential address, sex, and hospital record numbers) to conduct the probabilistic matching to create links. Clinical and health service details are not used. Therefore, while linkage officers are able to see names of individuals, they are not privy to the health conditions or services people received. The linkage officers create encrypted linkage keys, which are specific to each individual project.

2. The encrypted keys with identifying information are passed to the Data Custodians of the relevant data collections, so that clinical or health service details can be added. The patient identifying information is then removed.

3. The researcher receives encrypted linkage keys and service data specific to their project, with no patient identifiers.[199]

Through the separation of patient identifiers from clinical or service information, the WADLS allows researchers to conduct large-scale population studies while maintaining patient privacy, and enables Data Custodians to provide information to researchers without compromising patient confidentiality.[203] As a result, no individual party has access to unauthorised information (i.e., identifying details or clinical information from multiple data sources) through this process, thereby preserving the privacy of patient information and upholding professional obligations to maintain patient confidentiality (Figure 3).

Figure 3: WA Data Linkage System - Data Linkage Process[199]



The WADLS meets international best-practice standards, determined by experiences from the Oxford Record Linkage Study, Scottish Record Linkage System, Rochester Epidemiology Project and the Manitoba Centre for Health Policy.[121]

In terms of data validity, a linkage quality audit was performed in 1996 of the WADLS matching technique, and only 0.11% of links consisted of false-positive or false-negative matches.[121]

3.6.3 Description of study data sources

Data from three following statutory datasets were used for this study: Hospital Morbidity Data Collection (HMDC), Death Registry, and Integrated Road Information System (IRIS).

3.6.3.1 Hospital Morbidity Data Collection (HMDC)

The HMDC data are sourced from the WA DOH, and contains information for all public and private inpatient hospital activity in WA since 1970. The collection of this information is authorised under the *Hospital and Health Services Act 1927 (WA)*, and the *Health Services Act 2016.* HMDC data are instrumental for efficient and effective health monitoring, planning and evaluation of health services in WA, and the data are used for mandatory State and Federal-level health reporting requirements. The data undergoes an extensive quality assurance process prior to inclusion in the HMDC.[204]

Patient demographic and clinical information is recorded from patient discharge summaries, and therefore only completed hospital admissions (i.e., where the patient has been admitted and discharged from hospital) are included in the HMDC. Records extracted are based on date of discharge. Information in the HMDC includes patient demographics, clinically coded diagnoses and procedures, length of hospital stay, admission type and mode of patient separation from hospital. Clinically coded information is recorded using the International Classification of Diseases (Australian Modification), Australian Classification of Health Interventions and Australian Coding Standards (ICD AM, ACHI and ACS).[9, 10] Data are entered by trained administrative staff and clinical coders.

HMDC data are updated in the WADLS on a monthly basis.[199] A copy of the "Hospital Summary Inpatient Form", which summarises the information collected on an inpatient record, is included in Appendix A.

3.6.3.2 Death Registry

The death data for this study were sourced through the WADLB, who have been delegated custodianship of death registry data from the Registrar General of Births, Deaths and Marriages. This Registry contains records for all deaths occurring in WA since 1829,[205] however only death records from 1969 onwards have been digitised and made available for linked data projects.[199]

Following any death, a medical certificate is completed within 48 hours by a physician who was either responsible for the person's care before their death, or examined the person after death. All deaths are registered within 14 days of the date of death. The collection of this information is authorised by the *Births, Deaths and Marriages Registration Act 1998 (WA)*, which also authorises the use of death data for approved statistical purposes and research.[205]

Data available from the Death Registry includes all information recorded on a person's death certificate – such as demographic information, date of death and causes of death including underlying causes. Causes of death are coded by the Australian Bureau of Statistics (ABS) using ICD codes. Although the ICD codes used are the same as those used in the HMDC, the time periods that ICD versions have been applied in death data are based on calendar years rather than financial years as used in the HMDC, and based on the year of death registration (not date of death).[199]

Data are updated in the WADLS monthly.[199] A copy of the death certificate is attached in Appendix B.

3.6.3.3 Integrated Road Information System (IRIS)

Main Roads WA maintains the Integrated Road Information System (IRIS), which contains information on all crash events in WA since 1995. These data are used to report state-wide road crash statistics.[206] WA legislation requires that a traffic crash must be reported to police if:

- a crash results in bodily harm,
- the total value of property damage from the crash exceeds $3,000[#], or
- the owner or representative of any damaged property is not present.[206]

The IRIS data are person-based: each person from all vehicles involved in the crash have a separate record. IRIS data are initially sourced from WA Police, where road crash information is reported either by police officers attending a crash, or by a person involved in the road crash. Information recorded includes demographic details of persons involved, time/date and location of the crash, vehicle information (e.g. type, make, model, direction of travel), whether any injuries sustained were fatal or required medical attention, and circumstances of the crash (e.g. road and traffic control information, road and environmental conditions).[206] Main Roads WA add additional details to the police-reported data, such as latitude and longitude coordinates of crash locations, and road information such as road speed limits.

[#] The property damage value for mandatory police reporting increased from $1,000 to $3,000 in July 2008.

IRIS data used in this study were sourced through two mechanisms. From 1995 to late 2009, data for road crashes were reported to the police through the "P72" form, which is a paper-based form completed either by an attending police officer or a person involved in the road crash. An example of the P72 form is attached as Appendix C. From November 2009 onwards, the Online Crash Report Facility (OCRF) was introduced, enabling online self-reporting of crashes to the IRIS, in addition to police-reported data provided by the WA Police from the P-72 form. However, self-reported crashes through the OCRF are not available for data linkage, and therefore from late 2009, only crashes reported to IRIS by WA Police (i.e. where a police officer attended the crash) are included in this study.

3.7 Approvals

Approval for the use of linked health data for this project was granted by the WADLB, and Data Custodians of the HMDC, Death Registry and IRIS data, through the WADLB's approval processes.

Human research ethics approval for this project was obtained from the WA DOH Human Research Ethics Committee (Project Approval Number 2012/40). Reciprocal ethics approval was also obtained from The University of Western Australia Human Research Ethics Committee (Project Approval Number RA/4/1/5610).

3.8 Study methodology

3.8.1 Study terminology

For the purposes of this study, the following terminology is used, illustrated below with an example in Figure 4.

Cyclist: An individual person injured as a result of an accident while using a pedal cycle.

Accident: The event that resulted in the injury of a cyclist. ICD codes for ‘pedal cycle accidents’ were used to identify the cohort of hospitalised or fatally injured cyclists.

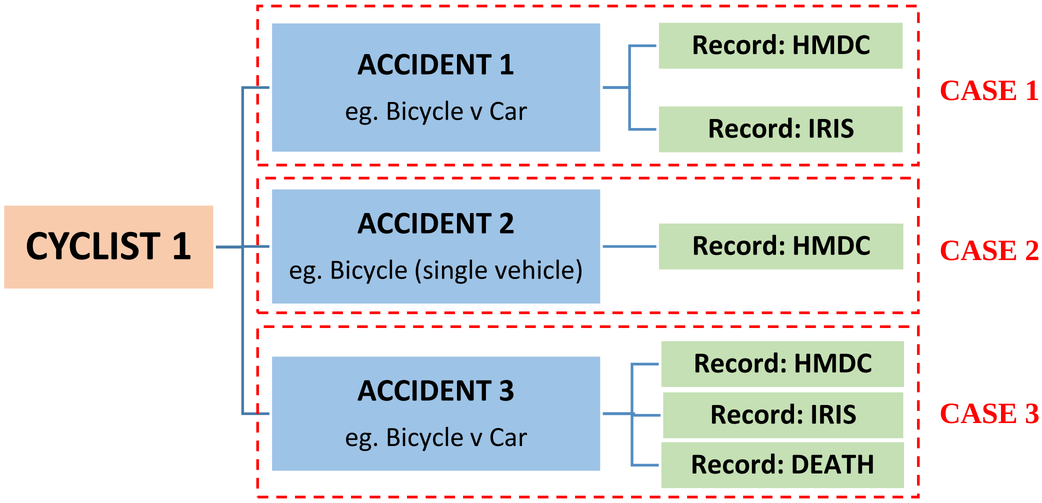
The term ‘accident’ will be used throughout this thesis when discussing events resulting in a cyclist’s hospital admission and/or death, and also applies where the cyclist had a IRIS record linked to a hospital admission or death where the crash was identified as an accident.

When referring to IRIS data in a general sense, beyond the immediate context of cyclists in this particular study, this will be referred to as ‘crash data’, as IRIS data are based on police crash reports. The intent behind crash events captured by the IRIS is unknown and thus cannot be referred to solely as accidents, unless confirmed through linkage to a clinically coded hospital record to indicate a non-deliberate cause of injury. Additionally, if the term ‘crash’ was used in other studies which are referred to in this thesis, the term will be adopted to avoid assumption of intent and the misinterpretation of results of other studies.

Record: refers to any hospitalisation episode, death or crash record obtained via the WADLB from each respective data source. A hospitalisation episode may consist of multiple hospital admissions if the patient was transferred to another hospital, statistically discharged and admitted, or had related admissions (further explained in Section 3.9.1.1). A cyclist may have multiple records within the same data source, or across different data sources.

Case: A case refers to the circumstances resulting in injury to a cyclist. Information relating to a case comprises of a hospital and/or death record, and may have a linked crash data record with all records relating to the same accident. An individual cyclist may have multiple cases if they have been hospitalised multiple times for injuries relating to different accidents.

Figure 4: Illustration of terminology used in this study



3.8.2 Cohort selection and service data extraction

3.8.2.1 Cohort selection

Rather than using a cohort sourced from police data that is known to be incomplete and then examining injury outcomes for a limited sample of the population, the cohort was derived from sources where all people were known to have sustained cycling injury. Therefore, the study population was identified from the HMDC and Death Registry, and this cohort could be further investigated to determine how circumstances of the accident played a role. This methodology is supported by findings from studies investigating pedal cycle crash rate underreporting and responds to their recommendations.[5, 6, 122]

As the HMDC only includes completed inpatient admission data, all cyclists included in this study had discharged from hospital within the study period (i.e. injured cyclists admitted but not discharged within the study period were excluded).

External cause of injury codes in the ICD coding system were used to identify cyclists in the HMDC who had been involved in a transport accident that resulted in injury serious enough to require admission to hospital, or deaths resulting from a cycling accident in the Death Registry.

ICD codes have been used by multiple studies to identify cycling injuries.[11, 12, 122] Given the longitudinal nature of this study, a range of ICD codes were used. In WA, ICD version 9 with Clinical Modification (ICD-9-CM) was used to code hospital separations from January 1988 to June 1999, and ICD version 10 with Australian Modification (ICD-10-AM) used from July 1999 to present.[9, 10] As the ICD codes in Death Registry data are coded by calendar year, ICD-10-AM was used from January 1999 onwards. A new edition of ICD-10-AM is released every two years, with amendments and updates to clinical codes,[9] however there were no changes to the codes used for the selection of the cohort across the ICD-10-AM editions applicable to this study (1st Edition to 7th Edition).[207]

The external cause codes that were used to identify the study population from the HMDC and Death Registry data collections are summarised below in Table 1. These codes are consistent with those used in other cycling injury studies.[11, 105] Injuries are coded with diagnosis codes *800* to *999* (ICD-9-CM) or *S00* to *T98* (ICD-10-AM). Medical injuries such as adverse events and complications of medical and surgical care were not examined as part of this study, as they have a different aetiology and means of prevention.

Table 1: ICD codes for identifying injury in cyclists

	ICD Version	
	ICD-9-CM	**ICD-10-AM**
External Cause Codes	E810 – E825: with 4th digit classification of .6 E826 – E829: with 4th digit classification of .1	V10 – V19
Injury Diagnosis Codes	800 – 999	S00 – T98

3.8.2.2 Service data extraction

Linked records relating to the members of the cohort were extracted from the HMDC, Death Registry and IRIS datasets in order to elucidate the complete picture of a cyclist's injury.

In addition to identifying injured cyclists, the data obtained from the HMDC also included additional information about cyclists' inpatient hospital admission, including demographic information, clinical diagnoses and length of stay. The latitude and longitude of cyclists' residential address recorded at the time of hospital admission was also obtained.

Death Registry records provided information on the date of death and primary and secondary causes of death. Deaths due to a road accident that did not have a linked hospital record were also included in the scope of this study to capture those deaths that occurred without hospital intervention.

Crash data from IRIS provided information on the accident event, such as the location and nature of the crash, helmet use, road and environmental features and whether or not other vehicles were involved. IRIS records for all persons, regardless of road user type, who were involved in an accident which included a cyclist were obtained in order to construct a comprehensive picture of the crash event, enabling analysis into the total number and type of vehicles involved in each accident. Latitude and longitude coordinates of the accident location were provided to enable geospatial analysis.

A list of variables used in this study from each data collection is attached in Appendix D.

3.8.3 Data preparation

3.8.3.1 Data cleaning

On receipt of the data from the WADLB, preliminary checks were performed. Duplicate records in the IRIS data were removed following confirmation from Main Roads WA. ICD coded cause of death was available from the Death Registry for deaths occurring from 1997 to 2010. For deaths outside this time period (1995 to 1996), the cause of death was provided as a free-text field, and this text was converted to ICD codes in consultation with the WA DOH Principal Clinical Coding Consultant.

For data items that were common to two or more datasets, comparisons were made to ensure consistency. Gender and age were compared across HMDC, Death and IRIS records, and discrepancies were referred back to the DLB for manual case review by Linkage Officers. Date of death was also checked between Death Registry and HMDC records where the patient was reported to have died in hospital.

3.8.3.2 ICD code mapping between ICD-9-CM and ICD-10-AM

Forward mapping of ICD-9-CM codes to ICD-10-AM was applied to enable consistency in analysis across the 16-year study period. Mapping was performed based on mapping files released by clinical coding authorities at the time of transition from ICD-9-CM to ICD-10-AM.[208]

The change from ICD-9-CM to ICD-10-AM resulted in more granular clinical codes for transport accidents, which presented challenges in analysing temporal trends relating to external causes and place of occurrence. Consultation with the Principal Clinical Coding Consultant and the Data Quality Team at the WA DOH concluded that ICD-9-CM codes could not be mapped with accuracy to ICD-10-AM codes at the external cause code level; and that place of occurrence codes prior to ICD-10-AM years were not standardised and could not be accurately mapped.

The differences between external cause and place of occurrence codes in ICD-9-CM and ICD-10-AM are described below.

External Cause Codes

ICD-9-CM transport accident codes are categorised firstly on the vehicle involved, with the victim identified through fourth character subdivisions. For example, *E813.6: Motor vehicle traffic accident involving collision with other vehicle, pedal cyclist injured.*[10] Conversely, ICD-10-AM code categorisations are based firstly on the victim and their mode of transport, with the type of accident identified through fourth character subdivisions. For example, *V13.4: Pedal cyclist injured in a collision with car, pick-up truck or van, driver, traffic accident*.[9]

Collision Type: The nature of the ICD-9-CM coding system broadly categorises accidents to “Motor Vehicle Traffic/Non-Traffic Accidents” or “Other Road Vehicle Accidents”. It was not possible to accurately distinguish the type of vehicle or object with which a pedal cyclist collided. The ICD-9-CM code for Pedal Cycle Accident (E826) includes collision with any vehicle or object that is not a motor vehicle – this includes animal, other pedal cycle, pedestrian, fixed or moveable object, railway train or fall from pedal cycle.[10] These categories are separately categorised in ICD-10-AM.[9] Therefore in this study, *collision type* was mapped to *motor vehicle involvement (yes/no)* rather than at the vehicle-specific level, to enable regression analyses covering the entire study period. Where ICD-10-AM was used, an accident was considered to involve a motor vehicle if the cyclist collided with a Car, Pickup Truck or Van, Heavy Transport Vehicle or Bus, or a Two- or Three-wheeled Motor Vehicle.

Accident Type (Traffic versus Non-Traffic Accidents): In terms of ICD coding, a traffic accident is defined as a transport accident which occurs on a public highway, with a public highway defined as the “entire width between property lines (or other boundary lines) of land open to the public as a matter of right or custom for the purposes of moving persons or property from one place to another”.[9] In ICD-9-CM, the distinction between traffic and non-traffic accidents is only made where a motor vehicle is involved. For accidents involving pedal cyclists that do not involve a motor vehicle no distinction is made between traffic and non-traffic accidents. Preliminary investigations in this study found that over 80% of records in each ICD-9-CM year did not involve a motor vehicle and therefore the distinction between traffic and non-traffic accidents could not be made. Traffic and non-traffic accidents are separately categorised in ICD-10-AM codes. Therefore in this study, analyses of accident type was restricted to the time periods pertaining to ICD-10-AM (July 1999 to December 2010).

Place of Occurrence Codes

Prior to the introduction of ICD-10-AM, place of occurrence codes reported in the HMDC were not based on ICD codes. The place of occurrence values could not be accurately mapped to an ICD-10-AM code equivalent due to lack of specificity. Similar to the analysis for accident type, place of occurrence was examined for cycling injury cases occurring between July 1999 and December 2010.

3.8.4 Measures of injury severity

3.8.4.1 International Classification of Disease based Injury Severity Scaling (ICISS)

For this study, ICISS was used to determine the severity of a cyclist's injuries.

Given that the cohort for this study was identified from ICD codes from hospital and death data, it was appropriate to use an injury scale that could be directly derived from retrospectively coded data for all members of the cohort. This methodology was similar to that previously used in other road injury studies.[13, 105, 115, 209] Furthermore, the incorporation of mortality data, in addition to hospital admission data, has been shown to improve the predictive ability of the ICISS.[210]

To calculate the ICISS, survival risk ratios (SRR) provided with HMDC data were used. SRRs were calculated by the WADLB for all injury admissions over the period 1995-2010, and linked with death data. The number of patients surviving a particular injury was divided by the total number of patients admitted to hospital in WA with that same injury, giving the likelihood a patient would survive that injury (Equation 1).[187]

Equation 1: Survival risk ratios (SRR)

$$SRR_{ICD_i} = \frac{Number\ of\ admissions\ with\ injury\ ICD_i\ where\ the\ patient\ survived}{Total\ number\ of\ admissions\ with\ injury\ ICD_i}$$

where ICD_i is the i-th ICD injury code

Using the SRRs in this study, an ICISS score was determined by multiplying the SRR of each injury diagnosis for a particular hospital episode where a cyclist was injured. Where a cyclist only had one injury, the ICISS will equate to the single SRR of the injury, alternatively the ICISS would be the product of 10 SRRs if the cyclist sustained 10 different injuries (Equation 2).

Equation 2: International Classification of Disease based Injury Severity Scaling (ICISS)

$$ICISS = SRR_{ICD_1} \times SRR_{ICD_2} \times \cdots \times SRR_{ICD_n}$$

where ICD_1 is the first injury sustained by the cyclist, ICD_2 is the second injury, ICD_n is the last injury sustained.

The lower the ICISS score, the lower the chance of survival and thus the greater injury severity. Injuries were classified as 'moderate', 'serious' or 'fatal' based on the ICISS. An accident was considered fatal if the cyclist had a death record where the primary or secondary cause of death was due to a cycling injury. This methodology is consistent with other injury studies performed in Australia[13, 14, 143, 147, 187, 211] and internationally.[212, 213]

Cut offs determined from Australian and New Zealand studies for ICISS were used in this study.[147, 212] A serious, non-fatal, ICD-9-CM coded injury was accepted as one with an ICISS score <0.96, which is a survival probability of 96%. For ICD-10-AM, a serious, non-fatal injury was considered to be an ICISS <0.941, reflecting a 94.1% chance of survival, or 5.9% risk of death[212] (Table 2). These ICISS cut-offs have also been used in other injury severity studies using hospital admission data.[14, 105, 161, 187, 212]

Table 2: Injury severity categories and associated ICISS cut-off scores

Injury Severity	ICD Version	
	ICD-9-CM	ICD-10-AM
Moderate	> 0.96	> 0.941
Serious	≤ 0.96	≤ 0.941
Fatal	Died from accident	Died from accident

As cyclists in this study had sustained injuries severe enough to at least be admitted to hospital, injuries in the current study which were not classified as serious or fatal were classified as being of moderate severity. These injuries were still known to be more severe than milder severity injuries which were out of scope of this study, such as those which presented only to EDs (i.e., not admitted), or those not requiring hospitalisation.

3.8.4.2 Killed or Seriously Injured (KSI)

Cases were further categorised into whether they were killed or seriously injured (KSI) to create a binary outcome to facilitate regression analyses. A cyclist who either sustained a fatal injury, or a non-fatal injury classed as a serious injury based on their ICISS, was classified as KSI. A cyclist sustaining moderate injury was not considered to be KSI. This methodology was previously adopted by WA studies using linked data to investigate severity of road crash injury.[13, 14, 187]

It is important to note that the WA Road Safety Commission (RSC) defines cases as ‘killed and seriously injured’ differently to the definition used in this study, it does not use ICISS. The WA RSC defines a road user as killed or seriously injured if the police report indicates that the injured person was admitted to hospital or died within 30 days of the accident; therefore references to the RSC’s definition of KSI will be referred to as ‘Killed and Seriously Injured – RSC (KSI-RSC)’ in this thesis.[4]

3.9 Analysis methods specific to study objectives

All statistical analyses and data manipulation were performed using SAS 9.3.[214] Analytic methods specific to each study aim are described below.

3.9.1 Aim 1: To quantify levels of severe and fatal cycling injury in WA, based on hospital and death data: 1995-2010

The purpose of this aim was to determine the number of cycling injury cases which resulted in hospital admission and/or death in WA between 1995 and 2010. Direct age-standardised rates of cycling injury cases were calculated over the 16 year study period, using the 2001 Western Australian standard population[215, 216] obtained from the ABS. Poisson regression was used to calculate rate ratios to evaluate changes in rates by year.

In order to quantify cycling injury cases, it was necessary to define episodes of hospital care relating to each accident, and merge records across datasets to determine the true number of injury cases. By doing so, this also established the overall study cohort who were further analysed in Aims 2 and 3 of this study.

3.9.1.1 Identification of hospitalised injury episodes

As HMDC records are based on hospital separations, to avoid over-counting of the number of hospitalisations relating to the same accident that might be due to hospital transfers and/or subsequent readmissions, it was necessary to link together separations for the same person to create a hospital 'episode' representing the complete period of hospital care received as a result of each cycling accident. The encrypted patient identifier provided by the WADLB was used to determine hospitalisations for the same person. All related records were known to be cycling-related from the use of external codes for cycling injury.

Transfers and Statistical Discharges

Continuous episodes of care were taken into account in this study by initially creating hospital episodes derived from hospital separations involving inter-hospital transfers and statistical discharges. A patient may be transferred to another hospital with facilities required to provide treatment, which results in the generation of multiple records reflecting the different care provided at different hospitals. Patients can also be statistically discharged and statistically admitted within the same hospital when the care type changes, e.g. from acute care to rehabilitative care. In such instances, although the patient will have multiple hospital separation records, the separations were considered to be part of one continuous episode of care. This approach has been used in other studies using linked HMDC data.[217, 218]

Subsequent Related Admissions

It is possible for a patient to be formally discharged from hospital, and readmitted for follow up care, for example, planned surgery or unexpected complications. Without an indicator such as a 'date of injury' field, it is difficult to determine if subsequent separations are related to the same event as the initial injury admission.

For this study, in addition to adjustments made for transfers and statistical separations, the identification of hospital episodes were further determined based on the following two criteria:

1. *Related subsequent separations occurring within 28 days of the previous separation*

A 28-day readmission period is also often used as a health indicator for inpatient hospital data in Australia.[219, 220] Furthermore, preliminary investigations of the hospital admission data in the current study, and also among cases with a linked crash record were undertaken to examine the use of a 28-day readmission period. It was assumed that if a person was admitted to hospital for a cycling injury, and was readmitted to hospital again within seven days for the same cycling injury, the two admissions were likely to be related. Based on this assumption, the use of a 28-day readmission period in this study is estimated to potentially underestimate the number of hospitalisations by only 1.4%, when compared to the use of a seven day readmission period.

Additionally, the availability of IRIS data meant that individual crash events could be distinguished for members of the study cohort with more than one IRIS crash. The minimum number of days between the first reported cycling crash record and subsequent cycling crash record among individuals who had more than one crash in this cohort was 35 days. Therefore, the use of a 28 day readmission period was unlikely to attribute hospitalisations to the incorrect crash record.[221]

2. *The first three characters of at least one diagnosis code (in any diagnosis field) matched at least one diagnosis code in the previous separation.*

All diagnosis codes (principal and additional) were used in the determination of related hospitalisations. Separations with the same diagnosis codes as previous separations (and within 28 days) were considered part of the same episode, ensuring that separations for follow up care were related to the same injury event. Matching the first three character diagnosis codes ensured that subsequent separations were related or similar to the previous separations, e.g. if the initial hospitalisation had a principal diagnosis '*S82.2 Fracture of shaft of tibia',* and a subsequent hospitalisation within 28 days had an additional diagnosis of '*S82.0 Fracture of lower leg,* *upper end of tibia'*, they were considered to be part of the same episode of care. This methodology was adopted because rehabilitation separations are assigned rehabilitation principal diagnosis codes, with codes for injuries listed in the additional diagnosis fields, as per Australian Coding Standards,[222] and therefore comparisons of only principal diagnosis codes would not have been sufficient. This methodology is similar to that applied in other Australian studies,[139] and was discussed in depth and reviewed by the WA DOH Principal Clinical Coding Consultant.

For these linked hospital separations, the cumulative length of stay in hospital was calculated, and the principal diagnosis code was retained from the first separation.

3.9.1.2 Merging of records across datasets

The encrypted patient identifier provided by the WADLB was not only used to determine hospitalisations relating to the same person as described above, but also identifying records across all three datasets that related to the same person.

First, hospital admission and death records were merged to form the cohort for the study. As data linkage projects in the field of cycling injury are limited, agreed criteria for linkages between data sources are lacking, and therefore preliminary investigations of the data were performed to determine appropriate allowances that needed to be made to consider potential links.

Hospitalisation and death records were merged for the same cyclist, based on death records having a cause of death relating to a cycling injury, and occurring within 30 days of hospital separation. Preliminary analyses showed that of cyclists who had a hospitalisation record for cycling injury and also died of cycling injuries, 48% died within 30 days of hospital separation. The remaining 52% of the cohort who died from cycling-related injuries died from cycling injuries more than 150 days after the date of initial hospital separation, and therefore were deemed unlikely to be related to the same cycling event.

Once the cohort was selected, crash data were merged based on the same encrypted patient identifier, in addition to the following two criteria.

1. *The crash date occurred within 14 days prior to the date of hospital admission*

As outlined above, it is difficult to accurately link a hospitalisation record with a crash record without a 'date of injury' field in the HMDC dataset, as a person can have multiple hospital admissions which may or may not relate to the same crash. In addition, there is the added complexity where the true impact of injuries from an accident may not be immediately realised, and a person may delay seeking medical attention.

By analysing hospital and IRIS records known to belong to the same person with the encrypted patient identifier, preliminary investigations showed that only 68% of hospital admissions occurred on the same day or day after the accident. A 14-day “accident-to-hospitalisation” buffer period was applied in this study, acknowledging that there may be delays in the seeking of medical treatment, particularly for blunt trauma often seen in cycling injury.[223] It was calculated that the use of a 14-day buffer period may potentially underestimate the number of crashes in this study by only 3%, compared to the use of a buffer period of one day (i.e., hospital admission on the same day as the crash).

2. *If the cyclist was not hospitalised, the crash date occurred within 30 days prior to the date of death.*

Preliminary investigations found that where the cyclist was not hospitalised, 98.2% of deaths occurred within 30 days of the accident. The remaining 1.7% of deaths occurred more than 70 days after the date of accident. Given the cyclists had no hospital admission record, they were deemed unlikely to be related to the same cycling accident. The use of a 30-day cut-off is consistent with WA Police’s method of reporting crashes resulting in death.[4]

3.9.2 Aim 2: To characterise severe and fatal cycling injury in WA in terms of sociodemographic, injury type, accident type and geo-spatial factors: 1995-2010

The characterisation of cycling injury in WA was divided into three objectives. The first, Objective 2a, investigated the characteristics of all cycling injury cases resulting in hospitalisation and death. Objective 2b examined two sub-cohorts based on whether the case had a linked IRIS record or not, to explore the differences between cycling injury cases where the accident was not reported to police (Sub-Cohort 1), and those which were reported (Sub-Cohort 2). Objective 2c completes this aim by analysing additional accident information obtained through IRIS data for cases in Sub-Cohort 2, including geo-spatial analysis based on accident coordinates.

3.9.2.1 Objective 2a: To characterise cyclist, injury and accident related factors in severe and fatal cycling injury (Overall Cohort)

Analysis for Objective 2a was based on the overall study cohort defined in Aim 1, based on hospital admission and death records. This descriptive analysis was divided into three parts: (i) demographic characteristics of injured cyclists, (ii) injuries that were sustained, and (iii) accident characteristics derived from HMDC data.

Characteristics of injured cyclists

This analysis focussed on ‘person-based’ sociodemographic characteristics of the cyclists. The age of cyclists were grouped into six categories: 0-5 years, 6-12 years, 13-17 years, 18-39 years, 40-65 years and over 65 years. These groups were chosen based on the ability to differentiate between children (under 18 years) and adults (18 years and over), while also distinguishing between children’s ages based on school age in WA at the time of this study: children aged 0-5 years are not yet at school, 6-12 years attend primary school, 13-17 years attend high school. Age standardised rates per 100,000 population were calculated over the 16-year study period using the 2001 standard Australian population.[215, 216] Due to the 5-year age group stratification of the standard Australian population made available by the ABS, children were defined in the age standardised rates as 0-19 years, and adults defined as 20 years and over.[216] Rate changes over time were statistically examined with Poisson regression.

A cyclist was considered to be Indigenous if the Indigenous status on their HMDC record was reported as Aboriginal and/or Torres Strait Islander. Where multiple HMDC records were linked for the same case, the Indigenous status reflected in the majority of HMDC records was used. A small proportion of cyclists were of unknown Indigenous status and were classified as non-Indigenous.

Geocoded addresses were used to investigate characteristics relating to cyclists' residential information.

Characteristics of cycling injuries

This analysis focussed on the type of injuries sustained by cyclists and the severity of such injuries. Categories of body region and injury type were based on ICD code classifications of the principal diagnosis of injury. Where no admission record was present, the primary injury coded in the death record was used. Length of stay (LOS) and injury severity (KSI, based on ICISS) were also described, in addition to further analysis pertaining to cyclists admitted to intensive care units (ICU). Independent t-tests were performed to compare the difference in average LOS and days in ICU, to determine if there were statistically significant differences in mean between the ICISS categories.

Accident characteristics (HMDC data)

Descriptive frequency analysis was performed for accident characteristics, based on cases with an inpatient record. Accident type (traffic versus non-traffic), the type of vehicle with which the cyclist collided and the place of occurrence were explored. Categories of each characteristic were based on external cause codes from ICD coding classifications. This analysis was restricted to July 1999 to December 2010, the years of ICD-10-AM, due to limitations of mapping between ICD-9-CM and ICD-10-AM for external cause and place of occurrence codes, as described in Section 3.8.3.2.

While ICD codes are used for coding cause of death data, external cause and place of occurrence codes are not captured consistently in death records. For this reason, only inpatient data were used for this analysis, and cases with only a death record were excluded.

3.9.2.2 Objective 2b: To characterise differences in severe and fatal cycling injury between cases with and without police-reported crash records (Sub-Cohort 1 versus Sub-Cohort 2)

The analysis for Objective 2b examined the differences between cycling cases where the crash was not reported to the police and cases where the crash was reported to police (i.e. had an IRIS record). These cases were divided into Sub-Cohort 1 and Sub-Cohort 2 respectively. This Objective was included to explore the impact of underreporting in police-reported data in WA, as described in Chapter 2, by comparing results from the two sub-cohorts.

Comparisons between the two sub-cohorts for categorical cyclist, injury and accident characteristics, as described above for Objective 2a, were analysed using chi-square tests. Mann-Whitney U tests were used to compare the significance of differences in continuous variables between the two sub-cohorts.

3.9.2.3 Objective 2c: To describe accident and geo-spatial characteristics of cycling injury in severe and fatal cycling injury, based on police-reported crash records (Sub-Cohort 2)

Further descriptive analyses were performed for the subset of the cohort which had a linked IRIS record (Sub-Cohort 2). This analysis examined accident characteristics based on additional information contained in the IRIS data, and also geo-spatial analysis based on geographical coordinates which were also provided in the IRIS data.

Accident Characteristics (IRIS data)

Characteristics examined in IRIS data included road and environmental conditions, the time accidents occurred, and also helmet use. Crash region (metropolitan versus regional) was investigated based on geocoded information. The number and types of vehicles involved in the accident were based on all linked IRIS records involved in the crash, not only the record of the cyclist. The day of the week, and time of the accident was analysed, categorised into the following groups: early morning – 6am to 9am; late morning – 9am to 12pm midday; early afternoon – 12pm midday to 3pm; late afternoon – 3pm to 6pm; evening – 6pm to 12am midnight. The early morning and late afternoon time periods also reflect peak traffic times seen in WA for people travelling to/from work and school.

Geo-spatial Analysis

Through spatial analysis, Objective 2c also analysed the geographic characteristics of cycling accidents resulting in severe or fatal injury, using geocoded accident data sourced from the IRIS. All spatial analysis was performed using ArcGIS Version 10.1. The Geocentric Datum of Australia 1994 (GDA94) coordinate system was used to map accident and residential coordinates (latitude and longitude). Spatial mapping of accident coordinates was performed to generate maps which illustrated cycling injury counts across the 16-year study period by Local Government Authorities (LGA). Crude rates of accident sites by LGA were also calculated and mapped to account for differences in LGA population sizes; age-standardisation of rates by LGA was not performed due to low numbers of cases when stratified by LGA.[216] The rate of accidents by LGA were calculated using denominators sourced from the WA estimated resident population (ERP) stratified by LGA, obtained from the ABS.[224] The count and rate of KSI accidents by LGA were also mapped. As rates were presented per 100,000 population, LGAs with populations less than 100,000 were shaded in the maps to indicate LGAs whose results should be interpreted with caution. Maps of WA LGAs are shown in Appendices E and F.

Accident location coordinates were sourced from the IRIS. Residential data were sourced from the HMDC dataset from the residential address at time of hospital admission, or from the Death Registry at the time of death. As each accident record was linked to the corresponding hospital or death record, the residential address were current at the time of each accident. Analyses of accident and residential locations were stratified into the Perth metropolitan area and regional (non-metropolitan) areas. Metropolitan Perth was defined as the Perth Statistical Division according to the ABS.[225]

Spatial joins between accident and residential address coordinates were used to calculate the distances between cyclists' residential address and accident location according to the road network. Supplementary road network and LGA boundary data were obtained from Landgate, WA's statutory authority for land ownership, via the Epidemiology Branch of the WA DOH. A route analysis layer was created in ArcGIS by using the Network Analyst extension, enabling the calculation of the shortest route using the road network between the residential address as recorded in the HMDC record, and accident site from the IRIS record.

The distance from accident location to the closest hospital was also calculated, which served as a proxy for an accident location's remoteness and accessibility to medical assistance.[226, 227] Geographic hospital location data were obtained from the Epidemiology Branch of the WA DOH. For this purpose, a hospital was defined as a medical facility which provided emergency department services. The distance between the accident site and closest hospital was calculated using the Network Analyst extension of ArcGIS to enable the calculation of the shortest route from the accident location to the nearest hospital using the road network.[228]

As distance analyses were based on the road network, accidents which did not occur on the WA mainland were excluded from analysis.

Care was taken not to identify individuals or individual crashes in output of the spatial analysis for confidentiality reasons. Where crash locations were mapped, maps were aggregated by area and mapped for large areas so no individual crash sites were identifiable.

3.9.3 Aim 3: To determine risk factors for being Killed or Seriously Injured (KSI) in cycling accidents in WA: 1995-2010

Aim 3 examined the factors that predicted whether an injured cyclist was KSI. Regression methods are used to find a model that best fits the data to describe the relationship between an outcome variable and multiple independent predictor (or explanatory) variables.[229] Logistic regression is used when the outcome is dichotomous,[229] and hence was used in Aim 3 to examine predictor variables for cycling injury cases, with the binary outcome of being KSI versus not being KSI. Across the inpatient admission, death and crash data sources, there were multiple factors that were likely to be involved in predicting KSI.

Aim 3 was divided into two objectives based on two study cohorts: i) to examine the differences between risk factors identified when all known cycling injury cases were included, and ii) identify risk factors found among cases only included in police reporting.

3.9.3.1 Objective 3a: To examine predictors of being KSI among severe and fatally injured cyclists (Overall Cohort)

In Objective 3a, all severe and fatal cycling injury cases in WA between 1995 and 2010 were included in the analysis.

This analysis included variables relating to cyclist sociodemographic factors, the type of injuries sustained, and accident characteristics which could be derived from inpatient admission data (e.g. accident and collision types).

Univariate models were initially used to determine statistical significance of variables for the outcome of being KSI.

In the development of multivariate logistic regression models, variables were included if univariate analyses demonstrated that they had a significant effect on being KSI, or if they had an underlying theoretical contribution to the outcome variable based on previous studies.[105, 136] Potential confounding variables such as age and gender were also included. Interactions between variables were investigated for statistical significance; where the interaction was statistically significant, odds ratios were calculated from interaction terms. For the inclusion of terms in the multivariate model, the significance level was relaxed to $p<0.1$.[229] The variables used in this model were age, gender, Indigenous status, body region of injury, accident type, motor vehicle involvement, and presence of a linked IRIS record.

Reference groups were chosen based on the lowest expected risk of being KSI based on current knowledge. For age groups, 40-54 year olds were chosen as the reference category, as this group was assumed to be more aware of road safety issues with greater road experience than the younger age groups, with less vulnerability than cyclists aged over 55 years.[230, 231] Children aged 0-5 years and 6-12 years were combined to one age group, as were cyclists aged 55 years and above, to ensure sufficient numbers in the age group categories to enable regression analyses. The variable *body region of injury* was derived from the principal diagnosis recorded for the hospital admission; where no admission occurred, the diagnosis listed as the coded cause of death was used.

3.9.3.2 Objective 3b: To examine predictors of being KSI among severe and fatally injured cyclists in a police-reported accident (Sub-Cohort 2)

For Objective 3b, only cases with a linked IRIS record were included in the analysis (Sub-Cohort 2). Although this sub-cohort contained less cases than the overall cohort used in Objective 3a, the inclusion of IRIS variables allowed more potential predictor variables to be examined.

This analysis included characteristics relating to the individual (e.g. age, gender, Indigenous status, injuries sustained, helmet use) in addition to road and environmental conditions (e.g. road alignment, speed limit), including those derived from spatial analysis (e.g. accident region, distance to closest medical facility).

The development of univariate and multivariate models, and selection of appropriate reference groups, were based on the same methodology as described for Objective 3a. Significant interactions between variables were also assessed among this cohort. The relationship between the use of helmets and being KSI was also examined in further detail in multivariate regression models which adjusted for age, gender and the involvement of motor vehicles in the crash.

The variables used in the multivariate model for this Objective were age, gender, Indigenous status, body region of injury, motor vehicle involvement, helmet use, distance to nearest medical facility, accident type, road alignment, road speed limit and accident region.

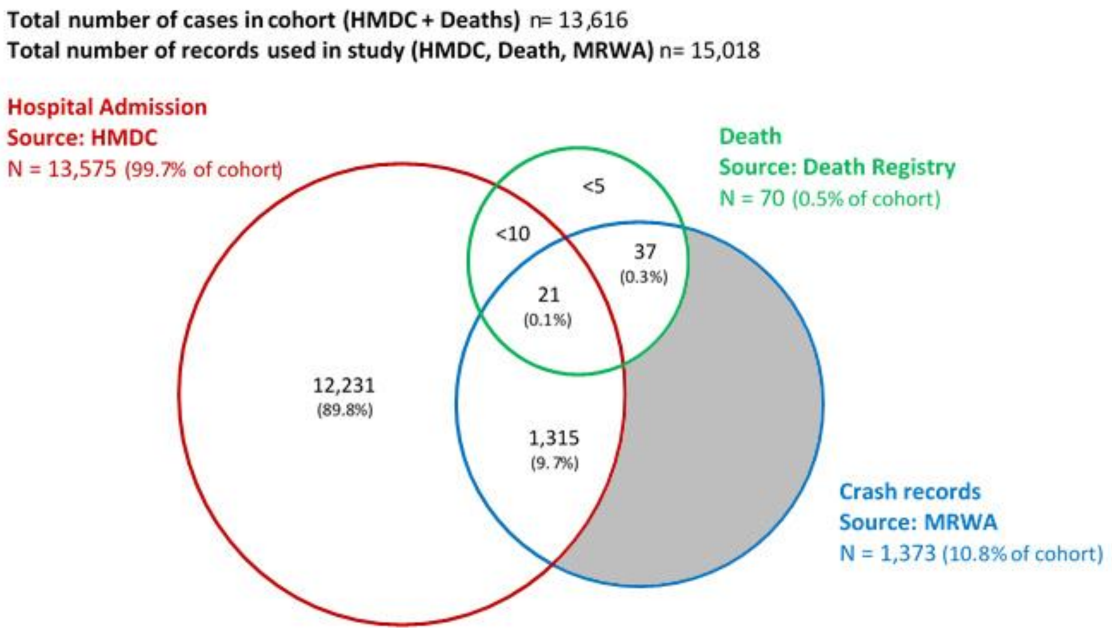
Chapter 4 Results

4.1 Aim 1: To quantify levels of severe and fatal cycling injury in WA, based on hospital and death data: 1995-2010

Figure 5 illustrates the relationship of the 15,018 records from the three data sources utilised in this study. Over the 16-year study period (1995-2010), there were a total of 13,645 hospital and death records related to cycling in WA. The majority of cycling injury cases only had a hospitalisation record (n=12,231, 89.8%). After admission records were merged to allow for inter/intra-hospital transfers and related readmissions, there were a total of 13,616 cases in the study cohort which were analysed in this study (Figure 5). The 13,616 cases belonged to 12,516 unique persons. The most number of cycling-related accident admission episodes belonging to the same person was four, with a median of one admission per injured cyclist.

Linked IRIS crash data were available for 1,373 cases (10.8% of the cohort). The grey area indicates cases that are out of scope for this study (i.e. IRIS records that do not have a linked hospitalisation or death record).

Figure 5: Number of hospital admission, death and crash records used in this study: 1995-2010

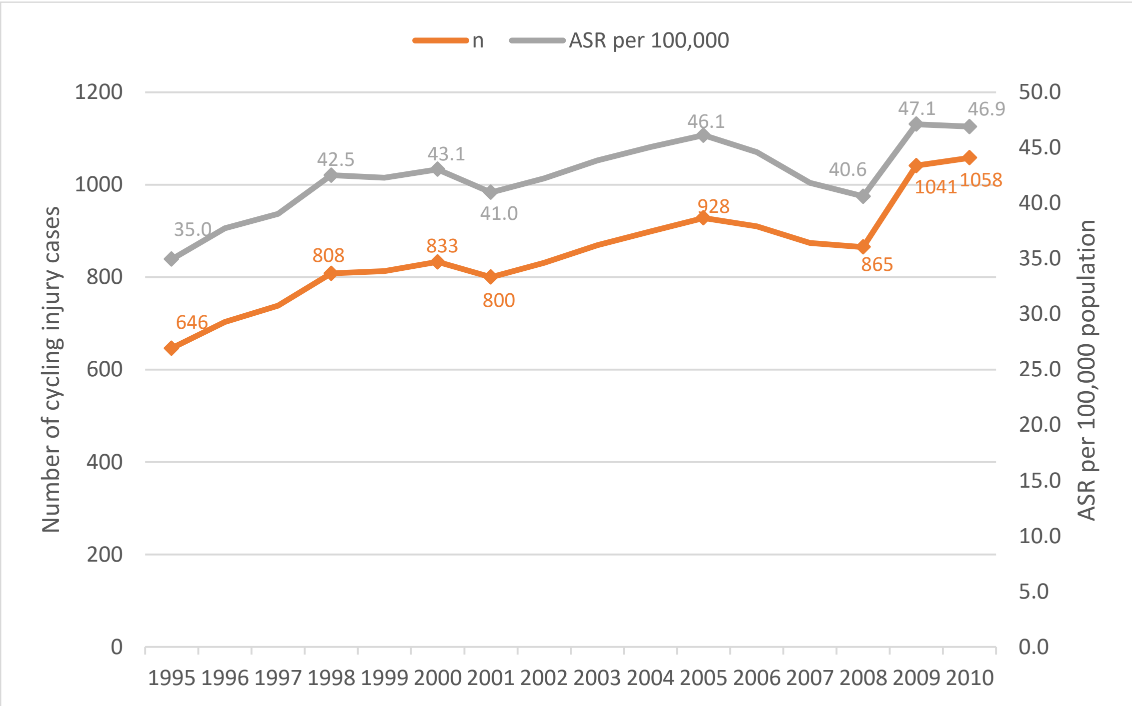


For confidentiality reasons, low figures have been suppressed.

Over the 16-year study period, the number of cycling injury cases increased by 64% from 646 in 1995 to 1,058 in 2010 (Figure 6). This represented a marginal though statistically significant annual crude rate increase from 37.2 to 46.2 cases per 100,000 population from 1995 to 2010 (RR: 1.01, 95% CI: 1.003-1.010, $p<0.01$). Age standardised rates per 100,000 population showed a rate increase when changes to the population were considered (Figure 6).

The number of deaths was highest in 1996 (10 cases, 1.4% of all hospitalised and fatal accidents), with no fatalities reported in 2009. On average, 0.5% of cycling injury cases were fatal per year.

Figure 6: Hospitalised and/or fatal cycling injury cases in WA – number and age-standardised rate per 100,000 population: 1995-2010



4.2 Aim 2: To characterise severe and fatal cycling injury in WA in terms of sociodemographic, injury type, accident type and geo-spatial factors: 1995-2010

4.2.1 Objective 2a: To characterise cyclist, injury and accident related factors in severe and fatal cycling injury in WA (Overall Cohort)

4.2.1.1 Characteristics of injured cyclists

4.2.1.1.1 Age and gender

The majority of the cohort were male (n=10,842, 79.6%), with males aged between 6 and 17 years comprising 43% of the total cohort (Table 3). The mean age of injured male cyclists was 22.8 years (SD=17.8 years), with female cyclists slightly older (23.8 years, SD=20.2 years). Over half of the cohort were aged under 18 years (n=8,087, 59.4%). Primary school aged children (6-12 years) comprised the largest individual age group (n=4,026, 29.6%) of those investigated.

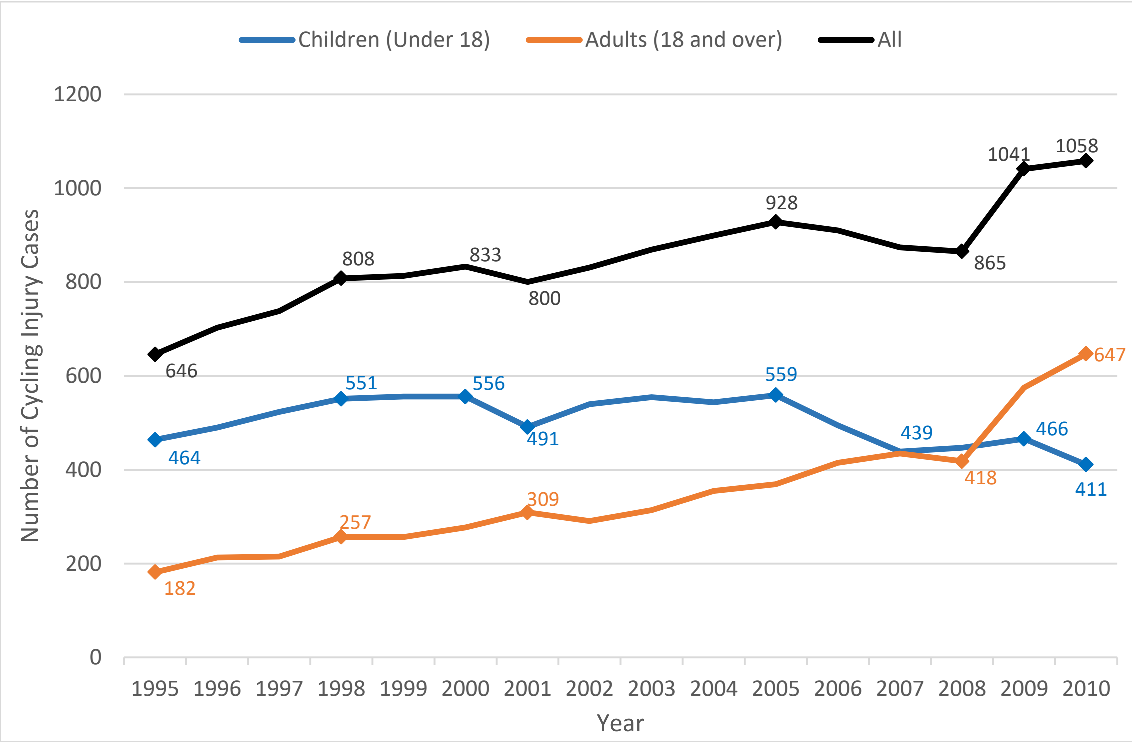
Table 3: Age and gender characteristics of severe and fatally injured cyclists in WA: 1995-2010

Age Group	Male		Female		All	
	N	%	N	%	N	%
0-5	629	4.6%	282	2.1%	911	6.7%
6-12	2,986	21.9%	1,040	7.6%	4,026	29.6%
13-17	2,857	21.0%	293	2.2%	3,150	23.1%
18-39	2,372	17.4%	497	3.7%	2,869	21.1%
40-54	1,162	8.5%	321	2.4%	1,483	10.9%
55+	836	6.1%	341	2.5%	1,177	8.6%
All	10,842	79.6%	2,774	20.4%	13,616	100.0%

For cyclists who died as a result of cycling injuries, the majority were aged over 18 years (n=51, 72.8%), and the average age of cyclists sustaining fatal injury was 41 years (SD=24.4 years). Males accounted for the majority of deaths (n=64, 91.4%).

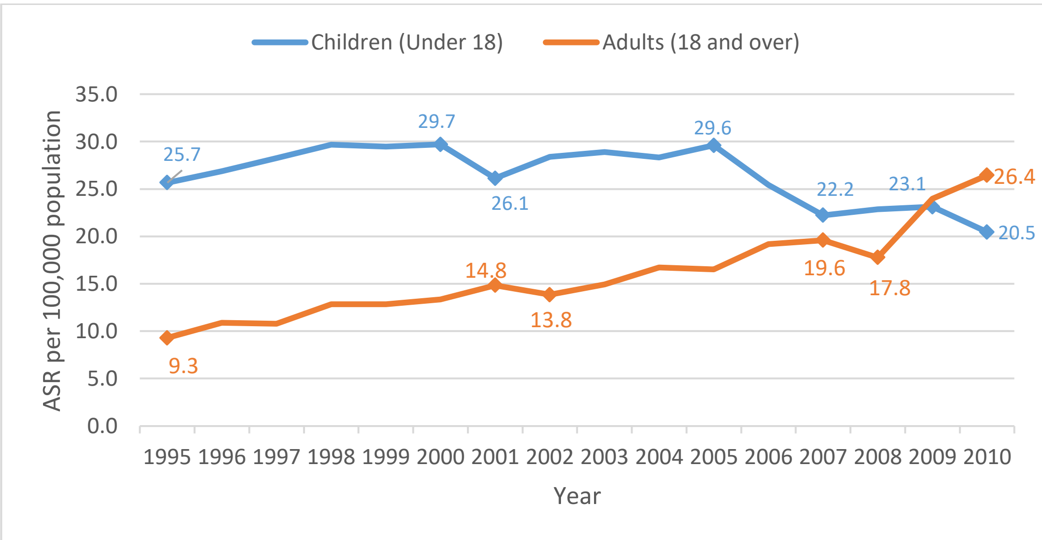
The numbers of cycling-related injury cases among all child age groups were generally stable until 2005, where after the number of injury cases decreased. Conversely, the counts among adults (aged 18 years and above) increased across the 16 year study period, increasing sharply from 2008 (Figure 7).

Figure 7: Trend in cycling injury by age group (children vs adults): 1995-2010



These observations held true when accounting for population growth, as shown by age-standardised rate of injury in Figure 8.

Figure 8: Cycling injury age-standardised rates by age group (children vs adults): 1995-2010



Rate ratios were calculated over the 16-year time period, and overall the rate of cycling injury in children aged under 18 years decreased over this period (RR: 0.98, 95% CI: 0.98-0.99). When analysed in separate models for four-year periods, there was an increase in cycling injuries in children between the years of 1995 and 1998 (RR: 1.05, 95%CI: 1.01-1.09). For each of the following four-year periods to 2010, a decrease was reported among children, however these findings were not statistically significant (Table 4). For adults, there was an overall increase in the rate of cycling injury over the 16-year study period (RR: 1.05, 95% CI: 1.05-1.06), with the highest increase seen between the years of 2007 and 2010 (RR: 1.12, 95% CI: 1.08-1.16).

Table 4: Cycling injury rate ratios, children and adults: 1995-2010.

Age Group	Year	RR	95% CI	p value
Children	1995-1998	1.05	1.01-1.09	0.01
(under 18 years)	1999-2002	0.98	0.94-1.01	0.20
	2003-2006	0.96	0.93-1.00	0.07
	2007-2010	0.97	0.92-1.00	0.11
	Overall: 1995-2010	0.98	0.98-0.99	<0.01
Adults	1995-1998	1.09	1.03-1.15	0.01
(18 years and over)	1999-2002	1.03	0.98-1.08	0.25
	2003-2006	1.07	1.02-1.11	0.01
	2007-2010	1.12	1.08-1.16	<0.01
	Overall: 1995-2010	1.05	1.05-1.06	<0.01

4.2.1.1.2 Indigenous status

The overwhelming majority of hospitalised or fatally injured cyclists in WA were non-Indigenous (n=12,928, 94.9%) (Table 5).

Table 5: Indigenous status of cyclists hospitalised or fatally injured in WA: 1995-2010

Indigenous Status	n	%
Indigenous	688	5.1%
Non-Indigenous/Unknown	12,928	94.9%
Total	13,616	100.0%

Of those who were Indigenous, 545 were male (79.2%), with children aged under 18 comprising the majority of Indigenous injured cyclists (n=565, 82.1%) (Table 6).

Table 6: Injured Indigenous cyclists, by age group and gender: 1995-2010

Age Group	Male		Female		Total	
	n	%	n	%	n	%
Children (Under 18)	441	80.9%	124	86.7%	565	82.1%
Adults (18 and over)	104	19.1%	19	13.3%	123	17.9%
Total	545	100.0%	143	100.0%	688	100.0%

4.2.1.1.3 Area of residence

Geocoded residential addresses from inpatient or death records of cohort members were available for 95.6% (n=13,021) of cases. Of these cases, 72.8% (n=9,474) lived in the Perth metropolitan area at the time of their cycling injury. The most common LGA in which injured cyclists resided were the City of Stirling (n=1,055, 8.1%) and the City of Joondalup (n=1,042, 8.0%). The regional LGA that was home to the most injured cyclists was the City of Mandurah, with 371 cases (2.8%). A full list of residential LGAs of injured cyclists is listed in Appendix G.

4.2.1.2 Characteristics of cycling injuries

4.2.1.2.1 Injuries sustained

Based on the primary diagnosis of injury, the head was the most common body region injured leading to hospital admission or death (n=3,823, 28.1%), followed by injuries to the elbow and forearm (n= 3,189, 23.4%), and injuries to the knee and lower leg (n=1,475, 10.8%) (Table 7). When grouped into broader body regions, injuries to upper limb regions (including the shoulder and upper arm, elbow and forearm, and wrist and hand) accounted for 39.2% (n=5,340) of all injuries, which were more common than injuries to the head and neck region (n=4,049, 29.7%), lower limb region (including the hip and thigh, knee and lower leg, ankle and foot) (n=2,368, 17.4%), and abdomen and thorax region (n=1,342, 9.9%). Just over 3% of primary diagnoses among injured cyclists were not injury diagnosis codes, rather diagnoses for conditions such as infections of skin or tissue, and mental and behavioural disorders.

Table 7: Body regions of hospitalised and fatal cycling injuries leading to hospital admission or fatality in WA: 1995-2010

Body Region of Injury	n	%
Injury to the Head/Neck	4,049	29.7%
Head	3,828	28.1%
Neck	211	1.5%
Head/neck - unspecified	10	0.1%
Injury to the Upper Limb	5,340	39.2%
Shoulder and upper arm	1,274	9.4%
Elbow and forearm	3,189	23.4%
Wrist and hand	872	6.4%
Upper limb - unspecified	5	0.0%
Injury to the Abdomen and Thorax	1,342	9.9%
Abdomen, lower back, lumbar spine and pelvis	932	6.8%
Thorax	410	3.0%
Injury to the Lower Limb	2,368	17.4%
Hip and thigh	553	4.1%
Knee and lower leg	1,475	10.8%
Ankle and foot	328	2.4%
Lower limb - unspecified	12	0.1%
Injuries involving multiple body regions	n.p.	n.p.
Injuries involving unspecified body regions	48	0.4%
Non-Injury Diagnosis	468	3.4%
Total	13,616	100.0%

For patient confidentiality reasons, counts less than five and associated percentages are not published ('n.p.')

Fractures were the most common type of injury sustained, with more than half of the cases having a type of fracture recorded (n=7,163, 52.6%) (Table 8). Intracranial injuries, including concussion, were the second most common type of injury (n=2,058, 15.1%) followed by open wound injuries (n=1,801, 13.2%).

Table 8: Types of hospitalised and fatal cycling injuries leading to hospital admission or fatality in WA: 1995-2010

Injury Type	n	%
Fracture	7,163	52.6%
Intracranial Injury, excluding those with Skull Fracture	2,058	15.1%
Open Wound	1,801	13.2%
Other	472	3.5%
Internal Injury of Chest, Abdomen and Pelvis	415	3.0%
Contusion with Intact Skin Surface	351	2.6%
Superficial Injury	329	2.4%
Dislocation	314	2.3%
Certain Traumatic Complications and Unspecified Injuries	306	2.2%
Sprains and Strains of Joints and Adjacent Muscles	300	2.2%
Injury to Nerves and Spinal Cord	63	0.5%
Injury to Blood Vessels	39	0.3%
Crushing Injury	5	0.0%
Total	13,616	100.0%

4.2.1.2.2 Injury severity

Most cyclists sustained injuries of moderate severity based on the ICISS score (n=12,103, 88.9%), with 10.6% of cases sustaining a severe injury (n=1,443) and 0.5% resulting in death (n=70) (Table 9).

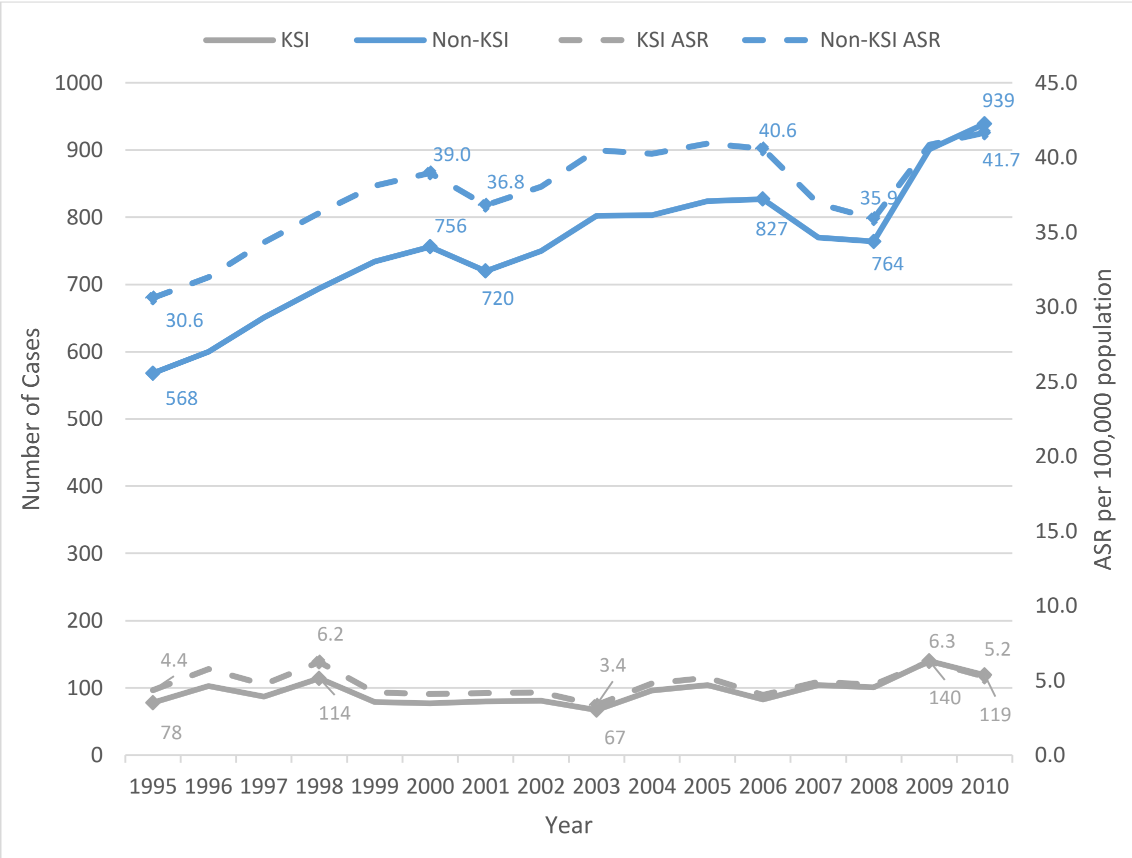
One in nine cases was classified as KSI (n=1,513, 11.1%), When analysed by age group, adults sustained injuries of greater severity more often than children (6.9% versus 4.2%).

Table 9: Severity of injuries sustained by cyclists in WA, defined by ICISS, by age group: 1995-2010

Injury Severity	Children (aged <18 years)		Adults (aged 18+ years)		All	
	n	%	n	%	n	%
ICISS						
Moderate	7,509	55.1%	4,594	33.7%	12,103	88.9%
Severe	559	4.1%	884	6.5%	1,443	10.6%
Fatal	19	0.1%	51	0.4%	70	0.5%
KSI						
Yes	578	4.2%	935	6.9%	1,513	11.1%
No	7,509	55.1%	4,594	33.7%	12,103	88.9%
Total	8,087	59.4%	5,529	40.6%	13,616	100.0%

The number of KSI cases increased from 78 cases in 1995 to 119 in 2010 (Figure 9). Age standardised rates increased from 4.4 to 5.2 KSI per 100,000 population (ASR: 1.21, 95% CI: 1.14-1.27).

Figure 9: Killed or Seriously Injured cycling injury cases in WA – number of cases and age-standardised rate per 100,000 population: 1995-2010



4.2.1.2.3 Length of hospital stay

For cases which involved a hospital admission (n=13,575), the average LOS was 3.2 days (SD=9.0 days), and the median LOS was 1.0 day (Table 10).

Cases with injuries of moderate severity had a median LOS of 1 day, and cases with severe injury stayed for a median of 5.0 days. For the 29 cases who died in hospital, the median length of stay in hospital was 2.0 days. Cases where the diagnosis was for an injury to the lower limb had the longest median LOS (3.0 days) relative to injuries occurring in other body regions.

Table 10: Length of stay in hospital by ICISS category and body region of injury

Parameter	n	Length of Stay (days)	
		Median	Mean (SD)
ICISS Group			
Moderate	12,103	1.0	2.1 (3.7)
Severe	1,443	5.0	12.3 (23.5)
Fatal	29	2.0	8.3 (14.3)
Body Region of Injury			
Abdomen	1,341	2.0	5.4 (10.8)
Head/Neck	4,043	1.0	3.2 (12.7)
Lower Limb	2,368	3.0	5.1 (7.7)
Upper Limb	5,340	1.0	1.7 (2.2)
Other Diagnosis*	483	2.0	5.6 (14.4)
Total	13,575	1.0	3.2 (9.0)

* *'Other Diagnosis' includes injuries to multiple regions, injuries of unspecified body region, and non-injury diagnoses*

4.2.1.2.4 Days in Intensive Care Unit (ICU)

Less than 2% of hospitalised cyclists (n=201, 1.5%) required treatment in an ICU. Of those cyclists who did, the median time spent overall in hospital was 10.0 days (Table 11). In terms of injury severity, ICU patients with severe injuries had a median LOS of 18.0 days while those with fatal injuries had a median LOS of 5.5 days. For these cyclists, the difference in average LOS between the moderate and severe ICISS groups was statistically significant (1.5 days and 18.0 days respectively, $p<0.001$), as was the difference in average LOS between the moderate and fatal groups (1.5 days and 5.5 days, $p=0.02$).

The median number of days spent in ICU for all injured cyclists was 2.0 days (Table 11). Cyclists suffering fatal injuries had an average of 5.3 days in ICU, compared to 5.7 days for severe cases (p=0.81) and 2.7 days for cases of moderate severity (p=0.01).

Table 11: Length of stay and days spent in ICU, among ICU patients by ICISS group

ICISS Group	n	Length of Stay (days)		Days in ICU (days)	
		Median	Mean (SD)	Median	Mean (SD)
Moderate	60	1.5	5.2 (9.2)	1.0	2.7 (3.4)
Severe	129	18.0	36.0 (47.3)	3.0	5.7 (6.5)
Fatal	12	5.5	13.7 (20.5)	3.5	5.3 (5.0)
Total	201	10	25.5	2.0	4.7

4.2.1.3 Characteristics of the accident (HMDC data)

Information regarding the nature and place of the accident was elicited from external cause and place of occurrence codes as determined by clinical coding for cases with a hospital admission record. As described in Chapter 3, the following results for *accident type*, c*ollision type* and *place of occurrence* relate only to data coded in ICD-10-AM (July 1999 to December 2010) (n=10,271).

4.2.1.3.1 Accident type

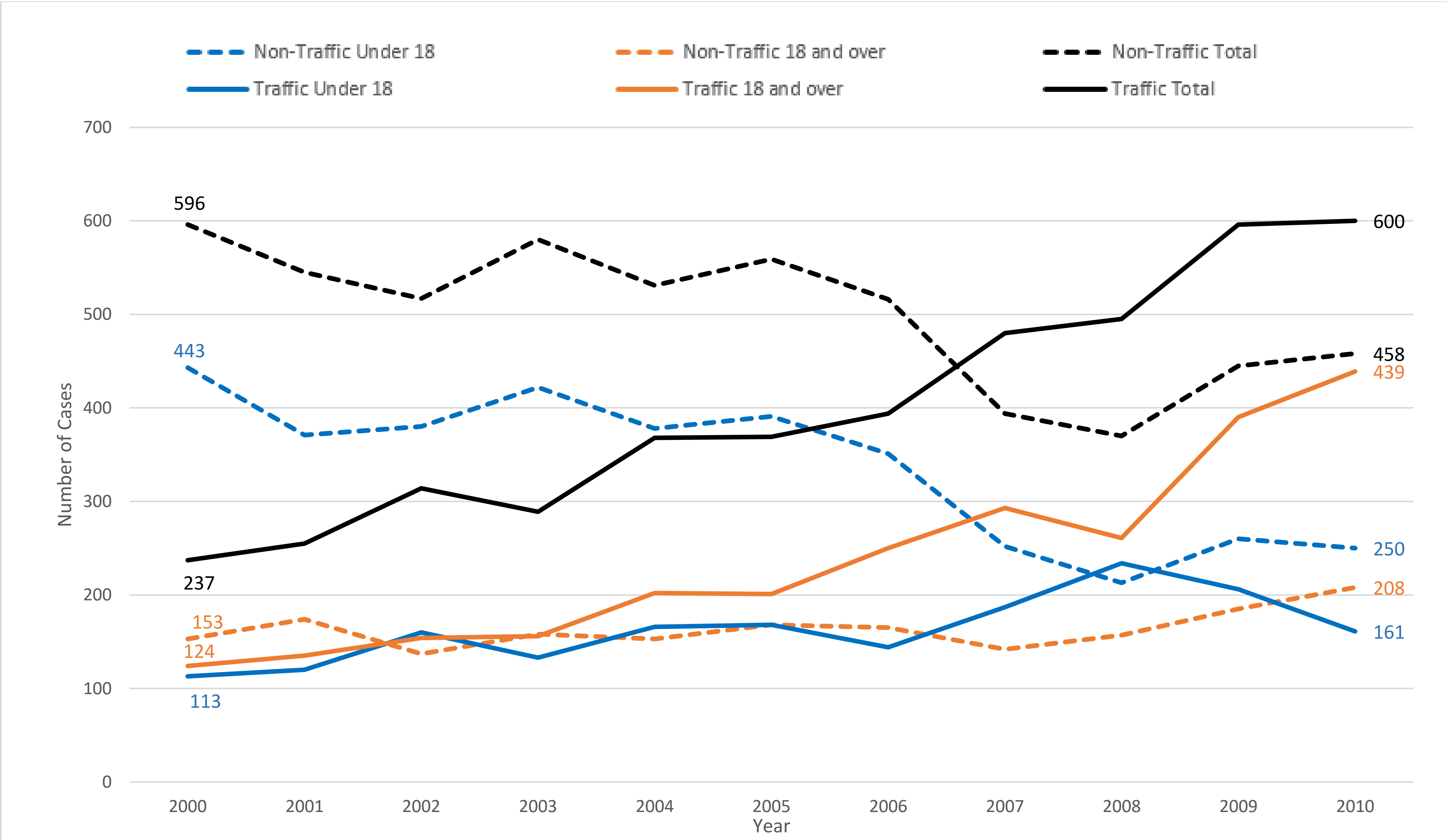
Most cycling accidents resulting in injury were non-traffic in nature (n=5,793, 56.4%), indicating that the accident occurred in a place that was not a public highway (Table 12). Children aged under 18 years involved in non-traffic accidents made up the largest proportion of accidents (n=3,919, 38.2%). Most traffic accidents were attributed to adults (n=2,626, 25.6%).

Table 12: Accident type of hospitalised and fatal cycling injury by age group: July 1999 – December 2010

Accident Type	Children (aged <18 years)		Adult (aged 18+ years)		All	
	n	%	n	%	n	%
Non-Traffic	3,919	38.2%	1,874	18.2%	5,793	56.4%
Traffic	1,852	18.0%	2,626	25.6%	4,478	43.6%
Total	5,771	56.2%	4,500	43.8%	10,271	100.0%

For the calendar years 2000-2010, there was a 2.5% average annual decrease in the number of non-traffic accidents (596 cases in 2000, falling to 458 in 2010), while the number of traffic accidents increased by 153% (237 in 2000 increasing to 600 in 2010) (Figure 10). The overall reduction in non-traffic accidents was attributable to a 44% reduction of non-traffic accidents in children (aged under 18 years) from 2000 to 2010, while the increase in traffic accidents was due to a 250% increase by adult cyclists (Figure 10).

Figure 10: Trends in accident type by age group (children vs adults): 2000-2010



4.2.1.3.2 Collision type

Non-collisions were the most common form of cycling accident, representing 66.4% of accidents among this cohort (n=6,818) (Table 13). Non-collisions included incidents such as falls and overturning without impact with any object or vehicle.[9] Of those involving collision, almost 1 in 10 accidents involved a car, pickup truck or van (n=978, 9.5%), and 1 in 20 involved a fixed or stationary object (n=486, 4.7%).

Most accidents involving a motor vehicle were traffic accidents (n=985, 95.0%), with collisions with a car, pickup truck or van the most common form of traffic accident (n=932, 95.3%) (Table 13). The majority of accidents not involving a motor vehicle were non-traffic accidents (n=5,741, 62.2%); of non-traffic accidents, most were non-collisions (n=4,956, 72.7%). However, 27.3% of traffic accidents were non-collision accidents (n=1,862). The relationship between collision type and accident type was statistically significant ($p<0.001$).

Table 13: Collision Type by accident type: July 1999 – December 2010

Collision Type	**Non-Traffic**		**Traffic**		**Total**	
	n	**%**	**n**	**%**	**n**	**%**
Motor Vehicle Involvement	*52*	5.0%	985	95.0%	1,037	10.1%
Car, Pickup Truck or Van	46	4.7%	932	95.3%	978	9.5%
Heavy Transport Vehicle or Bus, Railway Train, Two- or Three-Wheeled Motor Vehicle	6	10.2%	53	89.8%	59	0.6%
No Motor Vehicle Involvement	*5,741*	62.2%	3,493	37.8%	9,234	89.9%
Non-collision transport accident	4,956	72.7%	1,862	27.3%	6,818	66.4%
Fixed or Stationary Object	275	56.6%	211	43.4%	486	4.7%
Other Pedal Cycle	156	55.3%	126	44.7%	282	2.7%
Pedestrian or Animal	26	51.0%	25	49.0%	51	0.5%
Other non-motor vehicle or unspecified transport accident	328	20.5%	1,269	79.5%	1,597	15.5%
Total	5,793	56.4%	4,478	43.6%	10,271	100.0%

Table 14 shows collision types by age group, based on whether the cyclist was a child or adult. Over half of all child accidents did not involve a motor vehicle (n=5,401, 52.6%), with most accidents attributable to non-collisions (n=4,253, 41.4%). Adults were more often involved in accidents involving motor vehicles (n=667, 6.5%) than children (n=370, 3.6%).

Table 14: Collision type by age group: July 1999 - December 2010

Collision Type	Children (aged <18 years)		Adult (aged 18+ years)		All	
	n	%	n	%	n	%
Motor Vehicle Involvement	370	3.6%	667	6.5%	1,037	10.1%
Car, Pickup Truck or Van	352	3.4%	626	6.1%	978	9.5%
Heavy Transport Vehicle or Bus, Railway Train, Two- or Three-Wheeled Motor Vehicle	18	0.2%	41	0.4%	59	0.6%
No Motor Vehicle Involvement	5,401	52.6%	3,833	37.3%	9,234	89.9%
Fixed or Stationary Object	230	2.2%	256	2.5%	486	4.7%
Non-collision transport accident	4,253	41.4%	2,565	25.0%	6,818	66.4%
Other Pedal Cycle	118	1.1%	164	1.6%	282	2.7%
Other non-motor or unspecified transport accident	794	7.7%	803	7.8%	1,597	15.5%
Pedestrian or Animal	6	0.1%	45	0.4%	51	0.5%
Total	5,771	56.2%	4,500	43.8%	10,271	100.0%

4.2.1.3.3 Place of occurrence

Approximately one-third of accidents occurred on a public highway or road (n=3,325, 32.4%) (Table 15). Only 1.5% of accidents occurred on a cycleway (n=153), and 1.9% occurred on a sidewalk, footpath or pavement (n=192). Half of the accidents coded in hospital data did not specify a place of occurrence (n=5,237, 51.0%).

Table 15: Place of occurrence of hospitalised and fatal cycling injury: July 1999 – December 2010

Place of Occurrence	n	%
Home/Residential Institution	292	2.8%
School, Other Institution, Public Administrative Area	76	0.7%
Sports and Athletic Area	495	4.8%
Street and Highway - public highway, street or road	3,325	32.4%
Street and Highway - sidewalk	192	1.9%
Street and Highway - cycleway	153	1.5%
Trade and Service Area	19	0.2%
Industrial and Construction Area	6	0.1%
Farm	6	0.1%
Other specified place of occurrence	470	4.6%
Unspecified place of occurrence	5,237	51.0%
Total	10,271	100.0%

4.2.2 Objective 2b: To characterise differences in severe and fatal cycling injury between cases with and without police-reported crash records (Sub-Cohort 1 versus Sub-Cohort 2)

Characteristics of cases which did not have a linked police-reported IRIS records (Sub-Cohort 1) were compared to cases who did have a police-reported IRIS record (Sub-Cohort 2).

4.2.2.1 Characteristics of injured cyclists

4.2.2.1.1 Age, gender and Indigenous status

Cases with a linked crash record were on average older than those without a crash record (30.7 (SD=19.4) years versus 22.2 (SD=18.0) years; p<0.01); 61.9% of Sub-Cohort 1 were aged under 18 years, compared to 36.9% in Sub-Cohort 2 (Table 16). In Sub-Cohort 1, the greatest proportion of injured cyclists were 6-12 year olds (n=3,809, 31.1%), compared to Sub-Cohort 2, where most cyclists were aged 18-39 years (n=431, 31.4%) (p<0.0001).

In both sub-cohorts, males comprised the greater proportion of injured cyclists. Males were more likely to be involved in police-reported crashes, with 84.1% in Sub-Cohort 2 being male (n=1,155), compared to 79.1% in Sub-Cohort 1 (n=9,687) (p<0.0001).

Non-Indigenous cyclists made up the overwhelming majority of injured cyclists, in both sub-cohorts; 94.7% in Sub-Cohort 1 and 97.2% in Sub-Cohort 2.

Table 16: Cyclist characteristics: Sub-Cohort 1 vs Sub-Cohort 2

Cyclist Characteristic	Sub-Cohort 1 Without IRIS		Sub-Cohort 2 With IRIS	
	n	%	n	%
Age Group				
0-5 years	889	7.3%	22	1.6%
6-12 years	3,809	31.1%	217	15.8%
13-17 years	2,882	23.5%	268	19.5%
18-39 years	2,438	19.9%	431	31.4%
40-54 years	1,242	10.1%	241	17.6%
55+ years	983	8.0%	194	14.1%
Gender				
Male	9,687	79.1%	1,155	84.1%
Female	2,556	20.9%	218	15.9%
Indigenous Status				
Indigenous	649	5.3%	39	2.8%
Non-Indigenous / Unknown	11,594	94.7%	1,334	97.2%
Total	12,243	100.0%	1,373	100.0%

4.2.2.2 Characteristics of cycling injuries

4.2.2.2.1 Injuries sustained

Table 17 shows the characteristics of injuries sustained by Sub-Cohorts 1 and 2. In Sub-Cohort 1, injuries to head and injuries to the elbow and forearm accounted for the largest proportions of injuries (27.6% and 25.2% respectively). In Sub-Cohort 2, while head injuries accounted for the greatest proportion of injuries (32.7%), the next most common injury were knee and lower leg injuries (17.4%). Only 7.6% of injuries in Sub-Cohort 2 were attributed to the elbow and forearm (n=105).

Table 17: Body region of injury: Sub-Cohort 1 vs Sub-Cohort 2

Body Region of Injury	Sub-Cohort 1 Without IRIS		Sub-Cohort 2 With IRIS	
	n	%	n	%
Injury to the Head and Neck				
Head	3,379	27.6%	449	32.7%
Neck	173	1.4%	38	2.8%
Head or neck - unspecified	7	0.1%	*n.p.*	*n.p.*
Injury to the Upper Limb				
Shoulder and upper arm	1,151	9.4%	123	9.0%
Elbow and forearm	3,084	25.2%	105	7.6%
Wrist and hand	812	6.6%	60	4.4%
Upper limb - unspecified	5	0.0%	-	0.0%
Injury to the Abdomen and Thorax				
Abdomen, lower back, lumbar spine and pelvis	830	6.8%	102	7.4%
Thorax	316	2.6%	94	6.8%
Injury to the Lower Limb				
Hip and thigh	470	3.8%	83	6.0%
Knee and lower leg	1,236	10.1%	239	17.4%
Ankle and foot	309	2.5%	19	1.4%
Lower limb – unspecified	10	0.1%	*n.p.*	*n.p.*
Injuries involving multiple or unspecified body regions	32	0.3%	17	1.2%
Non-injury Diagnoses	*429*	3.5%	*39*	2.8%
Total	12,243	100.0%	1,373	100.0%

For patient confidentiality reasons, counts less than five and associated percentages are not published ('n.p.')

Patterns of injury type were similar for both sub-cohorts. Fractures were the most common form of injury, accounting for 53.1% of injuries in Sub-Cohort 1 and 48.1% of injuries in Sub-Cohort 2. Intracranial injuries were the second most common injury in both sub-cohorts (Table 18).

Table 18: Type of injury: Sub-Cohort 1 vs Sub-Cohort 2

Type of Injury	**Sub-Cohort 1** Without IRIS		**Sub-Cohort 2** With IRIS	
	n	**%**	**n**	**%**
Certain Traumatic Complications and Unspecified Injuries	260	2.1%	46	3.4%
Contusion with Intact Skin Surface	301	2.5%	50	3.6%
Crushing Injury	*n.p.*	*n.p.*	*n.p.*	*n.p.*
Dislocation	288	2.4%	26	1.9%
Fracture	6,502	53.1%	661	48.1%
Injury to Blood Vessels	30	0.2%	9	0.7%
Injury to Nerves and Spinal Cord	51	0.4%	12	0.9%
Internal Injury of Chest, Abdomen and Pelvis	364	3.0%	51	3.7%
Intracranial Injury, excluding those with Skull Fracture	1,793	14.6%	265	19.3%
Open Wound	1,667	13.6%	134	9.8%
Other	434	3.5%	38	2.8%
Sprains and Strains of Joints and Adjacent Muscles	275	2.2%	25	1.8%
Superficial Injury	275	2.2%	54	3.9%
Total	12,243	100.0%	1,373	100.0%

For patient confidentiality reasons, counts less than five and associated percentages are not published ('n.p.')

4.2.2.2.2 Injury severity

Sub-Cohort 1 reported a greater proportion of injuries of lesser severity than Sub-Cohort 2; 91.4% of injuries among Sub-Cohort 1 were of moderate severity compared to 66.1% in Sub-Cohort 2 (Table 19). Fatal injury was more frequent in Sub-Cohort 2 than Sub-Cohort 1 (4.2% and 0.1% respectively). Overall, Sub-Cohort 2 were more likely sustain serious or fatal injury, with 33.9% of Sub-Cohort 2 being KSI compared to only 8.6% of Sub-Cohort 1 ($p<0.0001$).

Table 19: Injury severity: Sub-Cohort 1 vs Sub-Cohort 2

Injury Severity	Sub-Cohort 1 Without IRIS		Sub-Cohort 2 With IRIS	
	n	**%**	**n**	**%**
ICISS				
Moderate	11,196	91.4%	907	66.1%
Serious	1,035	8.5%	408	29.7%
Fatal	12	0.1%	58	4.2%
KSI				
Yes	1,047	8.6%	466	33.9%
No	11,196	91.4%	907	66.1%
Total	12,243	100.0%	1,373	100.0%

4.2.2.2.3 Length of hospital stay and days in ICU

For cyclists who were hospitalised, the average length of stay in hospital for those with a linked crash record was significantly higher than those without a linked crash record (8.0 days and 2.7 days respectively, $p<0.01$) (Table 20). Sub-Cohort 1 had a median length of hospital stay of 1.0 day, compared to 2.0 days in Sub-Cohort 2 ($p<0.0001$).

Among those cyclists who were admitted to an ICU, Sub-Cohort 2 had a longer average length of stay than Sub-Cohort 1 (5.8 days and 3.9 days respectively, $p=0.03$). The median time spent in ICU by cyclists in Sub-Cohort 2 was 4.0 days, compared to 1.0 day for those in Sub-Cohort 1 ($p<0.0001$) (Table 20).

Table 20: Hospital length of stay and days in ICU: Sub-Cohort 1 vs Sub-Cohort 2 - Hospitalised cases only

Parameter		Sub-Cohort 1 Without IRIS	Sub-Cohort 2 With IRIS
Length of Stay (days)	n	12,239	1,336
	Median	1.0	2.0
	Mean (SD)	2.7 (6.5)	8.0 (20.3)
	Maximum	215	330
Days in ICU	n	*121*	*80*
	Median	1.0	4.0
	Mean (SD)	3.9 (5.7)	5.8 (5.9)
	Maximum	38	33

4.2.2.3 Characteristics of the accident

4.2.2.3.1 Accident and collision type

Accident characteristics sourced from the HMDC for the period July 1999 to December 2010 were also compared for Sub-Cohorts 1 and 2 (Table 21). Sub-Cohort 1 mainly consisted of non-traffic accidents (n=5,731, 61.0%), while the overwhelming majority of Sub-Cohort 2 were traffic accidents (n=810, 92.9%). Most accidents in Sub-Cohort 1 were non-collision accidents (n=6,753, 71.8%), whereas most accidents in Sub-Cohort 2 were accidents involving a car, pickup truck or van (n=713, 81.8%).

Table 21: Accident characteristics (HMDC): Sub-Cohort 1 vs Sub-Cohort 2: July 1999 – December 2010

Accident Characteristic	**Sub-Cohort 1** Without IRIS		**Sub-Cohort 2** With IRIS	
	n	**%**	**n**	**%**
Accident Type				
Non-Traffic	5,731	61.0%	62	7.1%
Traffic	3,668	39.0%	810	92.9%
Collision Type				
Car, Pickup Truck or Van	265	2.8%	713	81.8%
Fixed or Stationary Object	461	4.9%	25	2.9%
Heavy Transport Vehicle or Bus	13	0.1%	31	3.6%
Non-collision transport accident	6,753	71.8%	65	7.5%
Other Non-motor Vehicle	8	0.1%	n.p.	n.p.
Other Pedal Cycle	268	2.9%	14	1.6%
Other unspecified transport accident	1,574	16.7%	14	1.6%
Other vehicle	7	0.1%	8	0.9%
Pedestrian or Animal	50	0.5%	n.p.	n.p.
Total	9,399	100.0%	872	100.0%

For patient confidentiality reasons, counts less than five and associated percentages are not published ('n.p.')

4.2.2.3.2 Place of occurrence

The majority of Sub-Cohort 1 accidents had an unspecified place of occurrence (n=5,180, 55.1%). For accidents with a specification, the largest proportion of injury was seen for accidents occurring on a street or highway (27.0%). Sub-Cohort 2 accidents predominately occurred on a street or highway (n=789, 90.5%) (Table 22).

Table 22: Place of occurrence: Sub-Cohort 1 vs Sub-Cohort 2: July 1999 – December 2010

Place of Occurrence	**Sub-Cohort 1** Without IRIS		**Sub-Cohort 2** With IRIS	
	n	**%**	**n**	**%**
Home/Residential Institution	287	3.1%	5	0.6%
School, Other Institution, Public Administrative Area	76	0.8%	0	0.0%
Sports and Athletic Area	495	5.3%	0	0.0%
Street and Highway - public highway, street or road	2,536	27.0%	789	90.5%
Street and Highway - sidewalk	179	1.9%	13	1.5%
Street and Highway - cycleway	149	1.6%	n.p.	n.p.
Trade and Service Area	19	0.2%	0	0.0%
Industrial and Construction Area	6	0.1%	0	0.0%
Farm	6	0.1%	0	0.0%
Other specified place of occurrence	466	5.0%	n.p.	n.p.
Unspecified place of occurrence	5,180	55.1%	57	6.5%
Total	9,399	100.0%	872	100.0%

For patient confidentiality reasons, counts less than five and associated percentages are not published ('n.p.')

4.2.3 Objective 2c: To describe accident and geo-spatial characteristics of severe and fatal cycling injury, based on police-reported crash records (Sub-Cohort 2)

For the subset of the overall cohort which had links to IRIS data (Sub-Cohort 2; n=1,373), further characteristics relating to the accident event were examined. Additionally, with the geo-coordinates of the crash location available from the IRIS data, geo-spatial characteristics of these accidents were analysed.

4.2.3.1 Accident characteristics (IRIS data)

Accident characteristics examined included the types of other vehicles involved in the accident (where applicable), the road environment, nature of the collision, day and time of the accident and use of helmets.

4.2.3.1.1 Police attendance and involvement of other vehicles

Most IRIS reported accidents were attended by police (n=1,138, 82.9%) (Table 23). Most accidents involved a vehicle other than the pedal cycle of the injured cyclist (93.4%, n=1,282), and in most cases one other vehicle was involved (n=1,216, 88.6%) (Table 23). Single vehicle accidents, i.e., where the pedal cycle used by the injured cyclist was the other vehicle involved in the accident, were reported in 6.6% of accidents (n=91).

Table 23: Police attendance and number of other vehicles involved in the accident, Sub-Cohort 2: 1995-2010

Parameter	n	%
Police Attendance		
No	235	17.1%
Yes	1,138	82.9%
Number of Other Vehicles Involved		
1*	91	6.6%
2	1,216	88.6%
3	53	3.9%
4+	13	0.9%
Total	1,373	100.0%

* Single pedal cycle only, no other vehicle reported

Cars were involved in most of the accidents reported to the IRIS (n=1,124, 81.9%) (Table 24). Trucks or buses were involved in 5.4% of accidents (n=74), and at least one other bicycle was involved in 3.7% of accidents (n=51).

Table 24: Type of other vehicles involved in the accident, Sub-Cohort 2: 1995-2010*

Type of Other Vehicles Involved	n	%#
Car	1,124	81.9%
Truck or Bus	74	5.4%
Moped/Motorcycle	10	0.7%
Pedestrian	7	0.5%
Single bicycle only, no other vehicle reported	91	6.6%
Other pedal cycles	51	3.7%
Unknown vehicle	28	2.0%

* Figures show counts of accidents involving vehicle types shown; an accident may involve more than one of each vehicle type, or multiple vehicles of the same type. The total number of vehicle types will not sum the total number of cases in Sub-Cohort 2.

Percentage of Sub-Cohort 2 cases which involve each vehicle type

4.2.3.1.2 Road environment

The majority of Sub-Cohort 2 accidents occurred in the WA metropolitan area (n=1,097, 79.9%), in clear conditions (n= 1,164, 84.8%) and during daylight hours (n=1,070, 77.9%) (Table 25). Most accidents occurred at locations without traffic controls or signs (n=987, 71.9%) and on a level road (n=993, 72.3%). Nearly half of all accidents occurred on roads with a 60 kilometres per hour speed limit (n=649, 47.3%).

Table 25: Characteristics of the road environment, Sub-Cohort 2: 1995-2010

Road Environment Characteristic	n	%
Crash Region		
Metropolitan	1,097	79.9%
Regional	276	20.1%
Atmospheric Conditions		
Clear	1,164	84.8%
Raining	58	4.2%
Fog/Smoke/Dust/Mist	5	0.4%
Overcast	118	8.6%
Not Recorded	28	2.0%
Light		
Daylight	1,070	77.9%
Dawn Or Dusk	75	5.5%
Dark - Street Lights On	180	13.1%
Dark - Street Lights Off	11	0.8%
Dark - Street Lights Not Provided	15	1.1%
Not Recorded	22	1.6%
Traffic Control		
Intersection Traffic Lights	151	11.0%
Stop Sign	90	6.6%
Give Way Sign	120	8.7%
Zebra Crossing	6	0.4%
Rail Xing – Boom gates	5	0.4%
School Crossing	n.p.	n.p.
No Sign Or Control	987	71.9%
Traffic Lights & Give Way Sign	n.p.	n.p.
Mid-Block Traffic Lights	n.p.	n.p.
Not Recorded	6	0.4%
Grade		
Level	993	72.3%
Crest Of Hill	37	2.7%
Slope	305	22.2%
Not Recorded	38	2.8%
Speed Limit of Road		
Less than 50 km/h	16	1.2%
50 km/h	235	17.1%
60 km/h	649	47.3%
70 km/h	132	9.6%
80 km/h	54	3.9%
90 km/h	14	1.0%
100 km/h	10	0.7%
110 km/h	24	1.7%
Not Recorded	239	17.4%
Total	1,373	100.0%

For patient confidentiality reasons, counts less than five and associated percentages are not published ('n.p.')

4.2.3.1.3 Nature of collision

Most accidents were classified as right-angle crashes (n=711, 51.8%), followed by sideswipe (n=158, 11.5%), rear end (n=142, 10.3%) or right turn-through collisions (n=128, 9.3%) (Table 26).

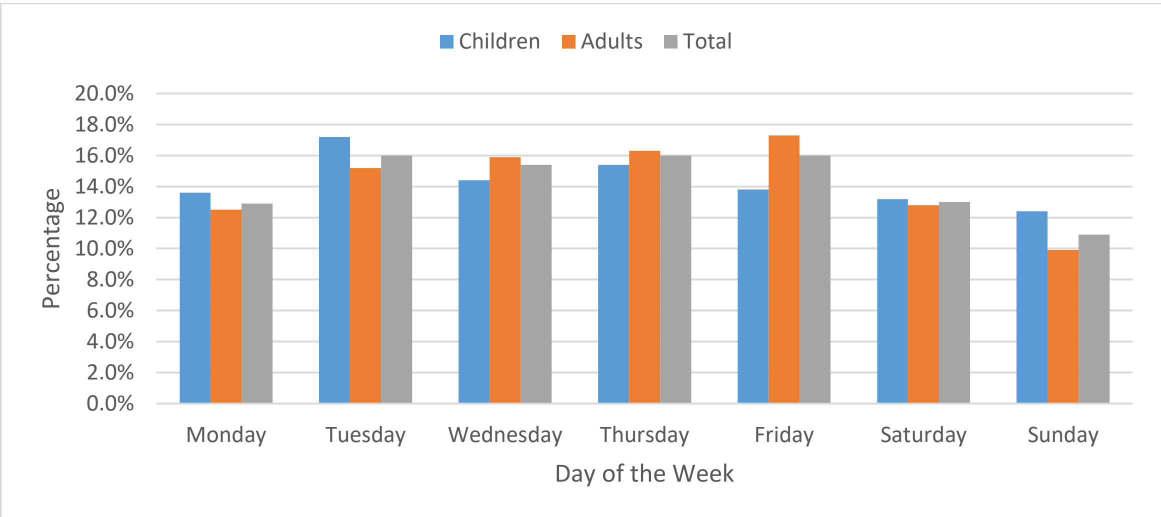
Table 26: Nature of cycling collision, Sub-Cohort 2: 1995-2010

Nature of Collision	n	%
Right Angle	711	51.8%
Sideswipe	158	11.5%
Rear End	142	10.3%
Right Turn Thru	128	9.3%
Non Collision	77	5.6%
Head On	28	2.0%
Hit Pedestrian/Animal/Object	28	2.0%
Not Recorded	101	7.4%
Total	1,373	100.0%

4.2.3.1.4 Accident day and time

Accident counts were generally distributed evenly by day of the week, although occurred least often on Mondays, Saturdays and Sundays. In terms of weekdays, both children and adults had the least number of accidents on Mondays, though accidents among children peaked on Tuesdays (17.2%), whereas the number of accidents among adults peaked on Fridays (17.3%) (Figure 11). The relationship between age groups and the day of the week the accident occurred was not statistically significant (p=0.42).

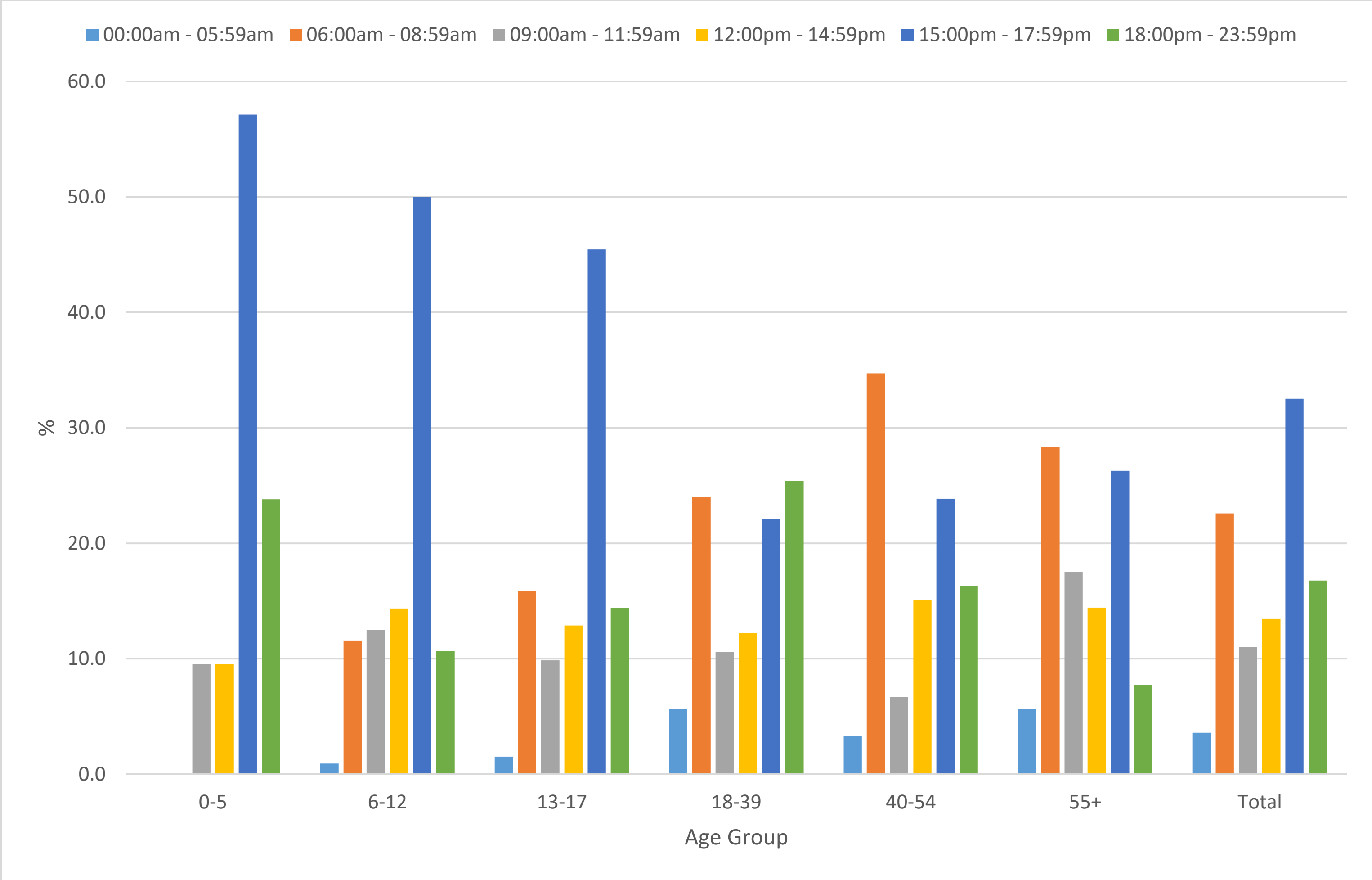
Figure 11: Percentage of accidents by day of the week, adults vs children, Sub-Cohort 2: 1995-2010



Most accidents occurred during the 6am-9am and 3pm-6pm periods, with 22.6% and 32.5% of accidents occurring between these times respectively (Figure 12).

The relationship between the time of day an accident occurred and age group was found to be significant ($p<0.01$). The hours between 3pm and 6pm accounted for the greatest proportion of crashes for all child age groups (0-5 years 57.1%, 6-12 year 50.0%, 13-17, 45.5%), while adults aged 40 years and over recorded the most accidents between 6am and 9am (40-54 years 34.7%, 55+ years 28.4%). Adults had accidents distributed more evenly across both morning and afternoon/evening time periods than children. Cyclists aged 18 to 39 years had similar accident occurrences between 6am and 9am, 3pm and 6pm and 6pm to midnight (24.0%, 22.1% and 25.4% respectively). Cyclists aged over 55 years sustained injuries most often in the morning, with 51.5% of accidents occurring by midday.

Figure 12: Age group by time period of accident, Sub-Cohort 2: 1995-2010



4.2.3.1.5 Helmet use

Helmets were recorded as being worn in 49.2% of crashes (n=675), however there was a high number of accidents where the use of helmets was not recorded (n=321, 23.4%) (Table 27). Among cyclists whose helmet wearing status was known (n=1,052), 64.2% were recorded as wearing helmets at the time of accident.

Table 27: Helmet Usage, Sub-Cohort 2: 1995-2010

Helmet Worn	n	%
Worn	675	49.2%
Not Worn	377	27.5%
Not Recorded	321	23.4%
Total	1,373	100.0%

4.2.3.2 Geo-spatial characteristics

Of the 1,373 Sub-Cohort 2 cases, 1,348 (98.1%) had available latitude and longitude data for the location of the accident. The 25 cases without latitude and longitude data were not statistically different to cases with these data in terms of age ($p<0.1$) or gender ($p<0.1$) (data not shown).

4.2.3.3 Accident location

4.2.3.3.1 All accidents

The geographical distribution of accidents within WA among Sub-Cohort 2 by WA LGA is shown in Figure 13. Appendices E and F illustrate the locations of all WA LGAs. Most accidents occurred in the Perth metropolitan region (n=1,051, 78.0%), with the most number of cycling injury accidents occurring in the City of Stirling (n=152). This was followed by the City of Joondalup (n=81), City of Swan (n=64) and City of Melville (n=64). The non-metropolitan LGA with the highest number of accidents was the City of Mandurah (n=40), followed by the City of Bunbury (n=29) (Table 28).

The risk of cycling injury in metropolitan WA was 4.7 cases per 100,000 population, and 2.7 cases per 100,000 population for regional WA (RR=1.74, 95% CI: 1.65-1.83). Among LGAs with more than 100,000 people, the City of Perth had the highest risk of injury (38.7 cases per 100,000 population), followed by the Town of Victoria Park (9.8 cases per 100,000) and the Town of Claremont (9.4 cases per 100,000) (Table 29). The level of risk in the Shires of Yalgoo and Peppermint Grove were higher than 10 cases per 100,000, however caution should be taken due to the low resident populations in these shires (less than 100,000) (Figure 14).

Figure 13: Number of cycling injury accidents in WA, by LGA region, Sub-Cohort 2: 1995-2010

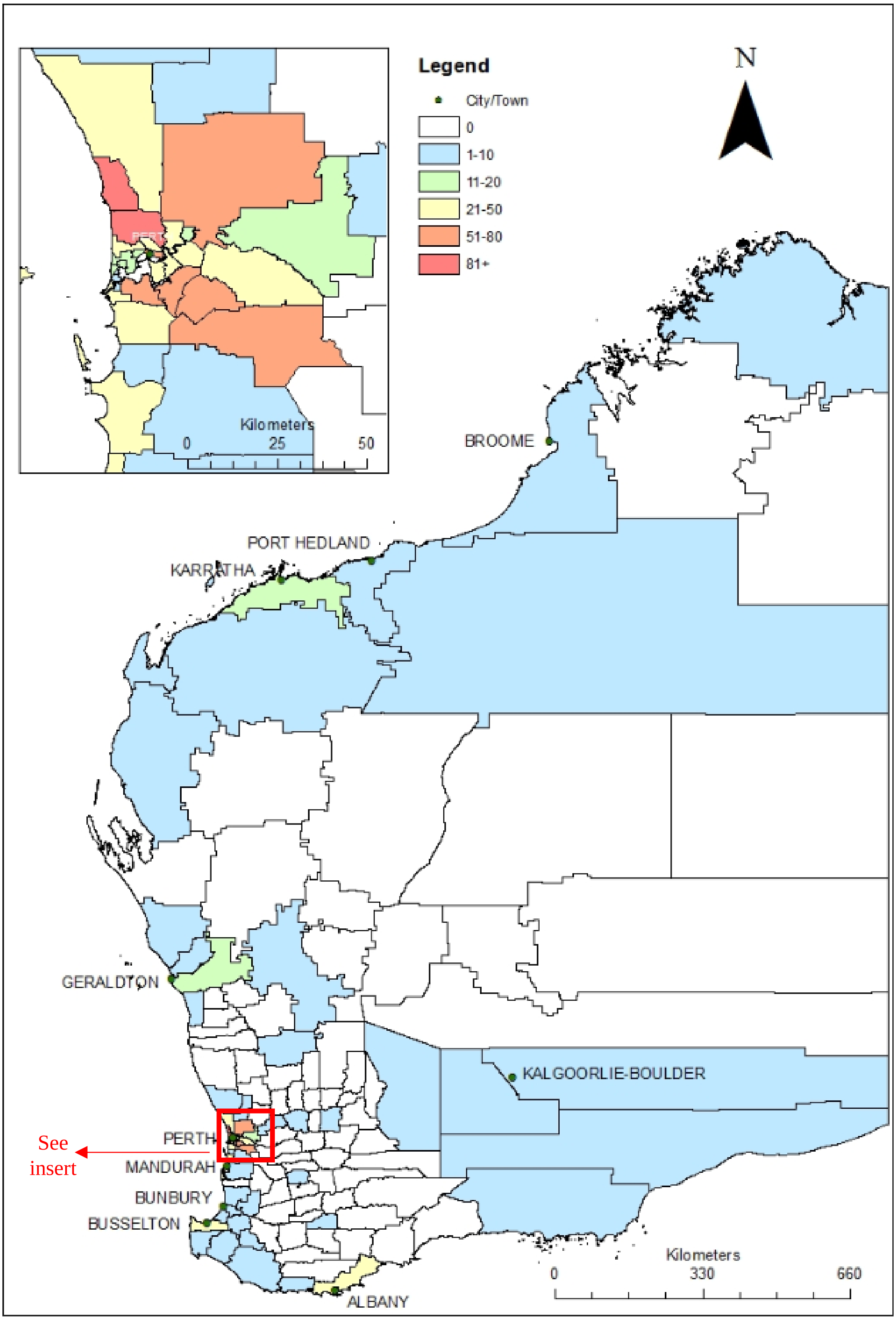
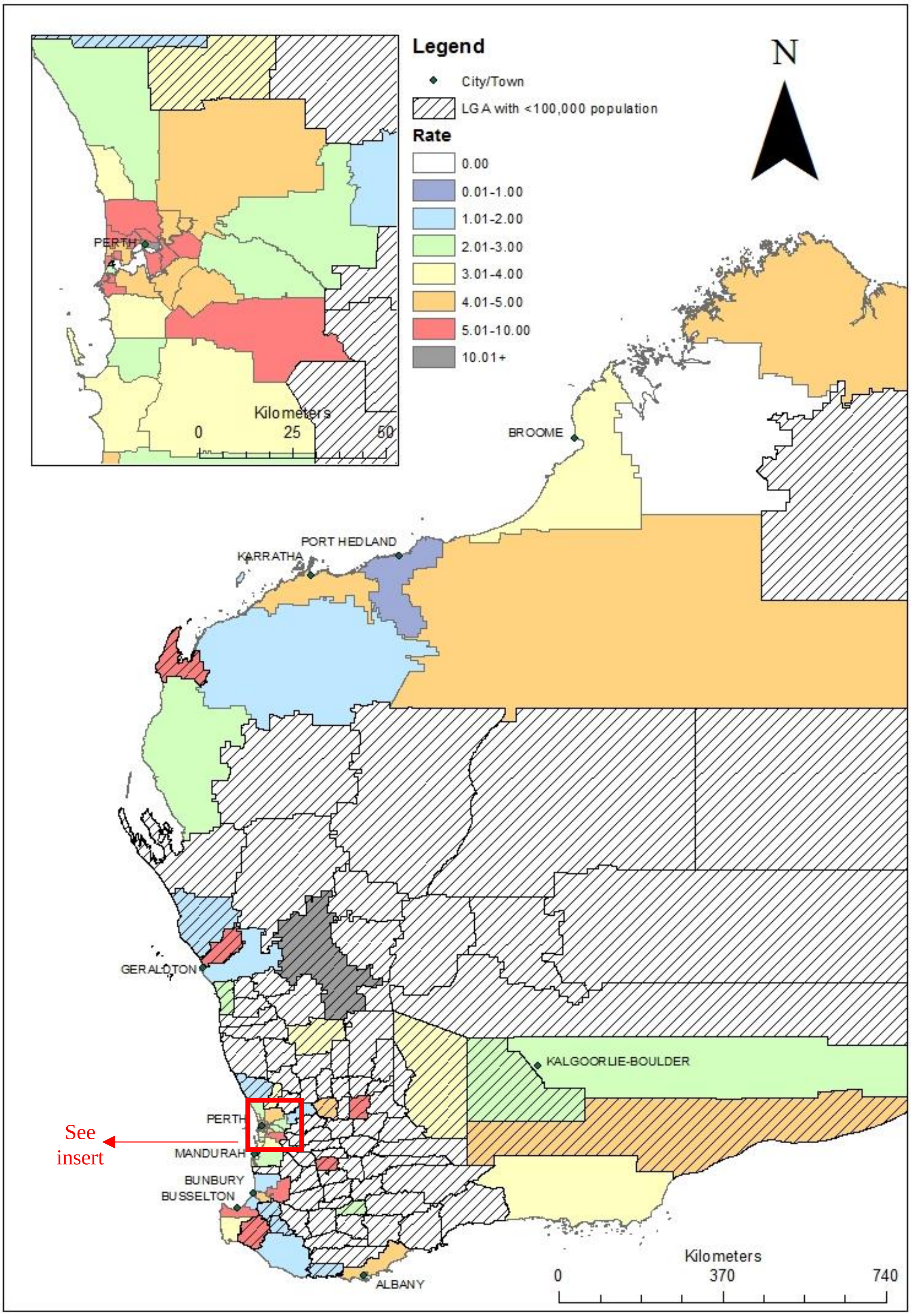


Figure 14: Cumulative incidence of cycling accidents in WA, by LGA region per 100,000 population, Sub-Cohort 2: 1995-2010



4.2.3.3.2 KSI accidents

For accidents where a cyclist was KSI, all regional areas had 10 or less events over the 16-year study period, with the exception of the City of Mandurah which had 20 accidents (Table 28). Within the WA metropolitan region, the City of Stirling had the most accidents where the cyclist was KSI (n=43), followed by the City of Swan (n=23) and the City of Joondalup (n=21) (Figure 15). Among the LGAs with 10 or more accidents, Mandurah had the highest proportion of KSI accidents, with 20 out of 40 (50.0%) accidents identified as being KSI. This was followed by the City of Cockburn (44.7%), and the Town of Victoria Park (40.0%) (Table 28).

The cumulative incidence of KSI injury was 60% higher in metropolitan WA than regional WA, with 1.6 cases and 1.0 cases per 100,000 population respectively. Among LGAs with greater than 100,000 people, the City of Perth was the LGA with the highest risk of serious injury (8.9 KSI cases per 100,000 population), followed by the Town of Victoria Park (3.9 cases per 100,000 population) and the Town of Cambridge (3.0 cases per 100,000) (Table 29). The Shires of Yalgoo, Kellerberrin and Nannup all had greater than five KSI cases per 100,000 population, however these results should be interpreted with caution as these LGAs had low residential populations (Figure 16).

Figure 15: Number of KSI cyclist accidents in WA, by LGA region, Sub-Cohort 2: 1995-2010

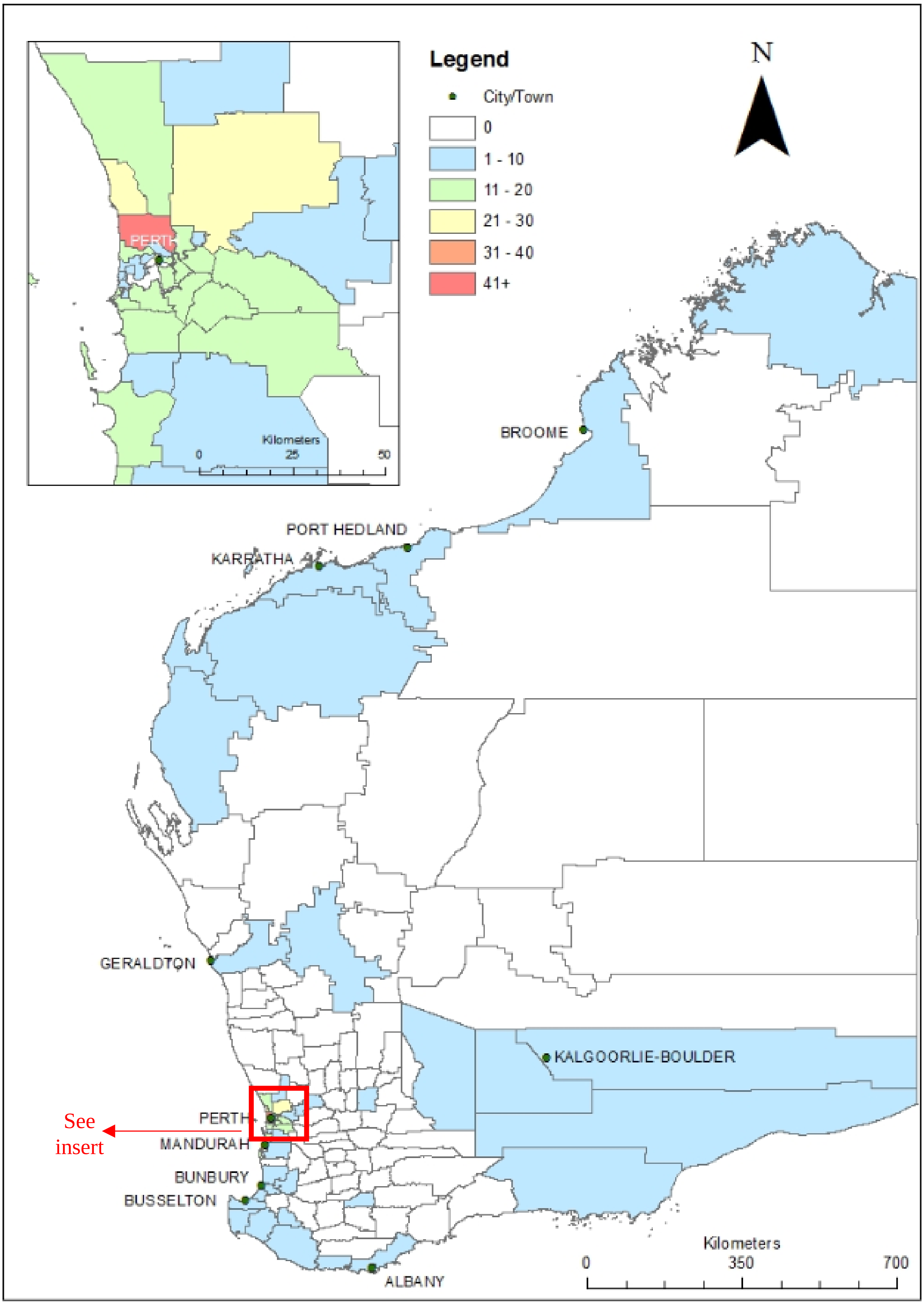


Figure 16: Cumulative incidence of KSI cyclist accidents in WA, by LGA region per 100,000 population, Sub-Cohort 2: 1995-2010

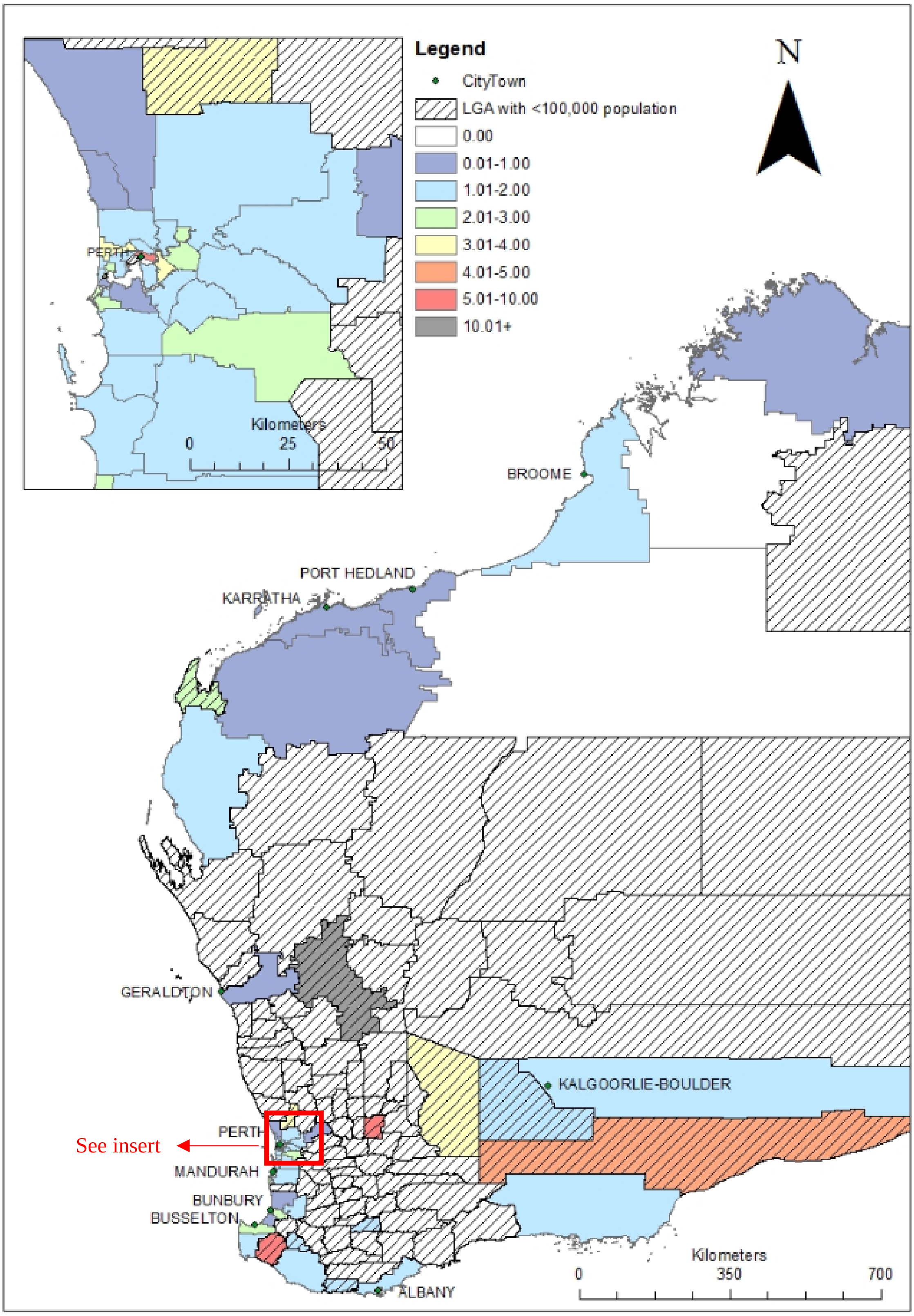


Table 28: Top 20 accident locations by LGA with severe or fatal cycling accidents, Sub-Cohort 2: 1995-2010

Ranking	LGA Name	Region Type	KSI Accidents	All Accidents	% KSI
1	City of Stirling	Metropolitan	43	152	28.3%
2	City of Joondalup	Metropolitan	21	81	25.9%
3	City of Swan	Metropolitan	23	64	35.9%
4	City of Melville	Metropolitan	15	64	23.4%
5	City of Gosnells	Metropolitan	16	61	26.2%
6	City of Perth	Metropolitan	14	61	23.0%
7	City of Canning	Metropolitan	16	54	29.6%
8	City of Armadale	Metropolitan	18	52	34.6%
9	City of Rockingham	Metropolitan	18	49	36.7%
10	Town of Victoria Park	Metropolitan	18	45	40.0%
11	City of Wanneroo	Metropolitan	14	44	31.8%
12	City of Mandurah	Regional	20	40	50.0%
13	City of Cockburn	Metropolitan	17	38	44.7%
14	City of Bayswater	Metropolitan	14	37	37.8%
15	City of Fremantle	Metropolitan	11	37	29.7%
16	Town of Cambridge	Metropolitan	12	35	34.3%
17	City of Belmont	Metropolitan	12	33	36.4%
18	City of South Perth	Metropolitan	12	32	37.5%
19	City of Bunbury	Regional	8	29	27.6%
20	City of Vincent	Metropolitan	8	29	27.6%

Table 29: Top 10 Cumulative incidence of injury by LGA - all accidents and KSI accidents, Sub-Cohort 2: 1995-2010

Ranking	LGA Name	Region Type	Cumulative incidence per 100,000
All Accidents			
1	City of Perth	Metropolitan	38.7
2	Town of Victoria Park	Metropolitan	9.8
3	Town of Claremont	Metropolitan	9.4
4	Town of Cottesloe	Metropolitan	9.0
5	City of Fremantle	Metropolitan	8.9
6	Town of Cambridge	Metropolitan	8.8
7	City of Subiaco	Metropolitan	6.9
8	City of Belmont	Metropolitan	6.7
9	Town of East Fremantle	Metropolitan	6.4
10	City of Vincent	Metropolitan	6.4
KSI Accidents			
1	City of Perth	Metropolitan	8.9
2	Town of Victoria Park	Metropolitan	3.9
3	Town of Cambridge	Metropolitan	3.0
4	Town of Claremont	Metropolitan	2.7
5	Shire of Dardanup	Regional	2.7
6	City of Fremantle	Metropolitan	2.6
7	City of Busselton	Regional	2.6
8	City of Belmont	Metropolitan	2.5
9	City of Mandurah	Metropolitan	2.4
10	Town of Bassendean	Metropolitan	2.2

4.2.3.4 Residential location of the cyclist

Of the 1,348 Sub-Cohort 2 cases available for geospatial analysis, 55 (4.1%) cases had residential locations which could not be geographically placed due to a lack of latitude and longitude coordinate data. These addresses could not be geocoded due to either not having a WA address (i.e. an unknown, interstate or overseas address) or a WA address that could not be geocoded (e.g. post office box). For those who had addresses that could be geocoded, most people injured resided in the metropolitan region (n=1,057, 78.4%).

4.2.3.4.1 Distance from residence to accident location

Two-thirds of cyclists had an accident in the same LGA in which they lived (n=908, 67.4%). Of the 1,293 cases where both residential and accident locations were known (95.9% of Sub-Cohort 2), the average distance by the road network from the cyclist's residence to the accident location was calculated (Table 30). For metropolitan accidents involving cyclists residing in the metropolitan area (n=1,057), the average distance from home was 4.82 kilometres (SD=7.08 kilometres). For regional cyclists involved in accidents in regional areas (n=213), the average distance from home to the site of the accident was 4.66 kilometres (SD=11.30 kilometres).

For metropolitan residents injured in accidents occurring in regional areas (n=12), the average distance from home was 110.42 kilometres (SD=84.71 kilometres) while regional residents injured in a metropolitan area (n=10) were on average 375.11 kilometres away from home (SD= 613.48 kilometres).

There were less than five cases where the police-reported accident did not occur on the WA mainland (i.e. occurred in WA island regions), and the distance from residence to accident location could not be calculated from the available data.

Table 30: Average distance (kilometres) between cyclist's residential address and location of the accident, by region of residence and region of crash

Region of Residence / Crash	n	Average Distance (SD), in kilometres[1]
Metropolitan Residence		
Crash Location - Metropolitan	1,057	4.82 (7.08)
Crash Location - Regional	12	110.42 (84.71)
Regional Residence		
Crash Location - Regional	213	4.66 (11.30)
Crash Location - Metropolitan	10	375.11 (613.48)

4.2.3.4.2 Distance from accident location to closest hospital

On average, the distance from the accident site to the closest hospital was 7.37 kilometres (SD=9.71 kilometres). As shown in Table 31, over three-quarters of accidents occurred within 10 kilometres of a hospital (n=1,038, 77.0%). Less than 1% of accidents occurred 50 kilometres or more from a hospital (n=7, 0.5%), of which less than five accidents occurred over 100 kilometres from a hospital.

Table 31: Distance from accident location to closest hospital*

Distance to Closest Hospital	n	%
< 5 kilometres	530	39.3%
5 - 9.99 kilometres	508	37.7%
10 - 19.99 kilometres	283	21.0%
20 - 49 kilometres	19	1.4%
50+ kilometres	7	0.5%

* Excludes cases where the accident did not occur on the WA mainland.

4.3 Aim 3: To determine risk factors for being killed or seriously injured (KSI) in cycling accidents in WA: 1995-2010

4.3.1 Objective 3a: To examine predictors of being KSI among severe and fatally injured cyclists (Overall Cohort)

Univariate odds ratios (ORs) for predictors of being KSI in the overall cohort are shown in Table 32. Males had 76% higher odds of being KSI than females (OR: 1.76; 95% CI: 1.51-2.06; p<0.01). The odds of being KSI increased with age, with cyclists under 40 years having significantly lower odds of being KSI than cyclists aged 40-54 years, and cyclists aged 55 and over were 61% at greater odds of being KSI than the 40-54 year old reference group (OR: 1.61; 95% CI: 1.33-1.93; p<0.01). Indigenous cyclists had a significantly lower odds of being KSI compared to non-Indigenous cyclists (OR: 0.59; 95% CI: 0.44-0.79; p<0.01).

Table 32: Cyclist-based predictors (univariate) of cycling injury for the outcome of being KSI (Overall Cohort)

Parameter	n	Odds Ratio	95% CI	p-value
Age Group				
0-12 years	4,937	0.26	0.21-0.31	<0.01
13-17 years	3,150	0.49	0.41-0.58	<0.01
18-39 years	2,869	0.64	0.54-0.76	<0.01
40-54 years	1,543	1.00	-	
55+ years	1,117	1.61	1.33-1.93	<0.01
Gender				
Male	10,842	1.76	1.51-2.06	<0.01
Female	2,774	1.00	-	
Indigenous Status				
Indigenous	688	0.59	0.44-0.79	<0.01
Non-Indigenous	12,928	1.00	-	

Table 33 shows the univariate ORs for the association between the outcome of KSI and body region of injury, accident type, motor vehicle involvement and the presence of a linked IRIS record. Based on the injury diagnosis, cyclists with injuries to the abdominal region were over 15-times greater odds of being KSI than cyclists with injuries to the upper limb (OR: 15.11; 95% CI: 12.36-18.47; p<0.01). Cyclists with head or neck injuries were almost seven-times greater odds of being KSI than those with upper limb injuries (OR: 6.89; 95% CI: 5.74-8.28; p<0.01).

Injured cyclists involved in traffic accidents had 84% higher odds of being KSI than cyclists injured in non-traffic accidents (OR: 1.84; 95% CI: 1.62-2.09; p<0.01). The odds of being KSI in an accident involving motor vehicles were 4.2-times higher than accidents which did not involve a motor vehicle (OR: 4.19, 95% CI: 3.69-4.75; p<0.01). Cases with a linked IRIS record were 5.5-times had greater odds to be KSI than cases without a linked IRIS record (OR: 5.49; 95% CI: 4.83-6.25; p<0.01).

Table 33: Predictors of cycling injury for the outcome of being KSI (Overall Cohort)

Parameter	Univariate		
	OR	**95% CI**	**p-value**
Body Region of Injury			
Abdomen	15.11	12.36-18.47	<0.01
Head/Neck	6.89	5.74-8.28	<0.01
Upper Limb	1.00	-	
Lower Limb	3.79	3.07-4.69	<0.01
Other Diagnosis*	5.05	3.71-6.86	<0.01
Accident Type			
Traffic	1.84	1.62-2.09	<0.01
Non-Traffic	1.00	-	
Motor Vehicle Involvement			
Yes	4.19	3.69-4.75	<0.01
No	1.00	-	
Linked IRIS Record			
Yes	5.49	4.83-6.25	<0.01
No	1.00	-	

* 'Other Diagnosis' includes injuries to multiple regions, injuries of unspecified body region, and non-injury diagnoses

Table 34 shows the multivariate regression model predictors of being KSI. The model included the variables age, gender, body region of injury, accident type, motor vehicle involvement and presence of a linked IRIS record. The model also adjusted for interactions between variables.

The variables accident type and motor vehicle involvement were removed as they were not statistically significant contributors to the model at the p<0.1 significance level. Similarly, interactions between age and gender, age group and linked IRIS record, and gender and body region were not statistically significant, and therefore removed from the final model.

Males were at higher odds than females to be KSI (OR: 1.76; 95% CI: 1.43-2.16; p<0.01), and age groups younger than the 40-54 year old reference group had a reduced odds of being KSI (0-12 years - OR: 0.06; 95% CI: 0.02-0.16; p<0.01; 13-17 years - OR: 0.18; 95% CI: 0.08-0.39; p<0.01; 18-39 years - OR: 0.53; 95% CI: 0.31-0.90; p<0.01). Accidents which were reported to police were 4.6-times greater odds of being KSI compared to accidents which were not reported (OR: 4.64; 95% CI: 2.64-8.16; p<0.01). Injuries involving the abdominal region were 13-times greater odds of being KSI than injuries of the upper limb (OR: 13.10, 95% CI: 7.91-21.71, p<0.01).

Table 34: Multivariate regression model for the outcome of KSI: adjusted for all variables and interactions, overall cohort[23]

Parameter	OR	95% CI	p-value
Gender			
Male	1.76	1.43-2.16	<0.01
Female	1.00	-	
Age Group			
0-12 years	0.06	0.02-0.16	<0.01
13-17 years	0.18	0.08-0.39	<0.01
18-39 years	0.53	0.31-0.90	0.02
40-54 years	1.00	-	
55+ years	1.59	0.89-2.83	0.12
Body Region of Injury			
Abdomen	13.10	7.91-21.71	<0.01
Head/Neck	7.85	4.86-12.68	<0.01
Upper Limb	1.00	-	
Lower Limb	1.67	0.90-3.11	0.1
Other Diagnosis[1]	3.33	1.52-7.31	<0.01
Linked IRIS Record			
Yes	4.64	2.64-8.16	<0.01
No	1.00	-	

Table 35: Multivariate regression model for the outcome of KSI: adjusted for all variables and interactions, overall cohort[2][3] (continued)

Interactions		Calculated OR	p value
Age Group x Body Region of Injury			<0.01
0-12	Injury to Abdomen	2.86	
	Injury to Head/Neck	1.62	
	Injury to Upper Limb	0.06	
	Injury to Lower Limb	0.40	
	Other Diagnosis[1]	0.86	
13-17	Injury to Abdomen	8.07	
	Injury to Head/Neck	3.12	
	Injury to Upper Limb	0.18	
	Injury to Lower Limb	0.45	
	Other Diagnosis[1]	1.00	
18-39	Injury to Abdomen	7.62	
	Injury to Head/Neck	5.34	
	Injury to Upper Limb	0.53	
	Injury to Lower Limb	1.00	
	Other Diagnosis[1]	0.62	
40-54	Injury to Abdomen	13.10	
	Injury to Head/Neck	7.85	
	Injury to Upper Limb	1.00	
	Injury to Lower Limb	1.67	
	Other Diagnosis[1]	3.33	
55+	Injury to Abdomen	13.49	
	Injury to Head/Neck	14.84	
	Injury to Upper Limb	1.59	
	Injury to Lower Limb	7.68	
	Other Diagnosis[1]	3.85	
Age Group x Linked IRIS Record			<0.01
0-12	Linked IRIS Record	0.90	
	No Linked IRIS Record	0.06	
13-17	Linked IRIS Record	1.39	
	No Linked IRIS Record	0.18	
18-39	Linked IRIS Record	2.78	
	No Linked IRIS Record	0.53	
40-54	Linked IRIS Record	4.64	
	No Linked IRIS Record	1.00	
55+	Linked IRIS Record	4.66	
	No Linked IRIS Record	7.38	
Body Region x Linked IRIS Record			<0.01
Injury to Abdomen	Linked IRIS Record	23.91	
	No Linked IRIS Record	13.10	
Injury to Head/Neck	Linked IRIS Record	21.95	
	No Linked IRIS Record	7.85	
Injury to Upper Limb	Linked IRIS Record	4.64	
	No Linked IRIS Record	1.00	
Injury to Lower Limb	Linked IRIS Record	5.46	
	No Linked IRIS Record	1.67	
Other Diagnosis[1]	Linked IRIS Record	39.38	
	No Linked IRIS Record	3.33	

[1] 'Other Diagnosis' includes injuries to multiple regions, injuries of unspecified body region, and non-injury diagnoses

[2] Adjusted for all variables in the model.

[3] *Indigenous status*, *motor vehicle involvement* and *accident type* variables, and *age group x gender*, *age group x linked IRIS record*, *gender x body region* interactions were removed from the model at p<0.1 significance level

There were significant interactions between the variables *age group* and *body region of injury* ($p<0.01$), *age group* and *linked IRIS record* ($p<0.01$), and *body region of injury* and *linked IRIS record* ($p<0.01$). The effect of the interactions on significant variables were calculated from interaction estimates, and results are presented in Table 34.

Body region of injury increased the effect of age for the outcome of being KSI. Injury to the abdomen had the largest effect; relative to the reference group of upper limb injuries, with the OR increasing from 0.06 for 0-12 year olds to 2.86 when abdominal injuries were considered; and from 0.18 to 8.07 for 13-17 year olds and 0.53 to 7.62 for 18-39 year olds.

The presence of a linked IRIS record increased the effect of both age and body region of injury for the outcome of being KSI. Cyclists aged 0-12 years involved in a police-reported accident and thus have a linked IRIS record were 0.84-times higher odds of being KSI than cyclists of the same age group without a linked crash record. Cyclists with a head injury resulting from a police-reported cycling accident were 14-times greater odds of being KSI than cyclists with head injuries where the accident was not reported (OR Injury to Head/Neck without linked IRIS record: 7.85; OR with linked IRIS record: 21.95); injuries to the abdomen which were reported to police had a 10-fold increase in odds of being KSI compared to those which were not reported (OR without IRIS record: 13.10; OR with IRIS record: 23.91).

4.3.2 Objective 3b: To examine predictors of being KSI among severe and fatally injured cyclists in a police-reported accident (Sub-Cohort 2)

Further regression analysis was performed on cases which had a IRIS record (Sub-Cohort 2), to incorporate additional accident characteristics, including those determined through spatial analysis.

Table 36 shows results of the univariate analysis for KSI among cases from Sub-Cohort 2, for characteristics relating to the cyclist. Similar to the analysis for the overall cohort (Objective 3a), cyclists aged under 40 years were at a lower risk of being KSI than cyclists aged 40-54 years and over. Males were 59% more likely to be KSI than females (OR: 1.59, 95% CI: 1.15-2.10, p<0.01).

Table 36: Cyclist-based predictors of cycling injury for the outcome of being KSI (Sub-Cohort 2)

Parameter	n	OR	95% CI	p-value
Age Group				
0-12 years	239	0.69	0.47-1.00	0.05
13-17 years	268	0.80	0.55-1.14	0.22
18-39 years	431	0.74	0.53-1.03	0.07
40-54 years	247	1.00	-	
55+ years	188	1.31	0.89-1.93	0.17
Gender				
Male	1,155	1.59	1.15-2.10	<0.01
Female	218	1.00	-	
Indigenous Status				
Indigenous	39	0.76	0.37-1.54	0.44
Non-indigenous	1,334	1.00	-	

Table 37 shows univariate results of accident-based predictors for the outcome of KSI among Sub-Cohort 2. Accidents among this cohort resulting in abdominal injury had greater odds of being KSI compared to accidents where the upper limb was the principal reason for injury (OR: 6.62, 95% CI: 4.30-10.19, p<0.01). Cyclists with injuries to the head and neck region had 4.4-times greater odds of being KSI than those resulting from upper limb injuries (OR: 4.39, 95% 3.03-6.38, p<0.01).

Accidents occurring in metropolitan areas were at 1.5-times greater odds of resulting in a cyclist being KSI (OR: 1.49, 95% CI: 1.14-1.95, p<0.01). Where an accident occurred in a location which was greater than 20 kilometers away from the closest medical facility, the odds of the cyclist being KSI were three-times higher than if the accident had occurred within five kilometres of a medical facility (OR: 2.98, 95% CI: 1.33-6.71, p=0.03). Accidents occurring on roads with a speed limit of 90 kilometres per hour or higher was 2.85-times greater odds of being KSI than accidents occurring in 50 kilometres per hour speed zones (OR: 2.85, 95% CI: 1.14-7.16, p=0.03).

Table 37: Accident-based predictors of cycling injury for the outcome of being KSI (Sub-Cohort 2)

Parameter	Univariate		
	OR	**95% CI**	**p-value**
Body Region of Injury			
Abdomen	6.62	4.30-10.19	<0.01
Head/Neck	4.39	3.03-6.38	<0.01
Upper Limb[1]	1.00	-	
Lower Limb	1.64	1.08-2.48	0.02
Other Diagnosis[1]	9.76	5.19-18.37	<0.01
Accident Type			
Traffic	1.04	0.60-1.80	0.90
Non-Traffic	1.00	-	
Motor Vehicle Involvement			
Yes	0.85	0.65-1.13	0.27
No	1.00	-	
Accident Region			
Metropolitan	1.49	1.14-1.95	<0.01
Regional	1.00	-	
Alignment			
Curve	1.06	0.75-1.50	0.75
Straight	1.00	-	
Helmet Use			
Worn	0.71	0.55-0.92	<0.01
Not Worn	1.00	-	
Unknown	0.54	0.39-0.75	<0.01
Road Speed Limit			
50km/h	1.00	-	
60km/h	1.03	0.75-1.41	0.85
70km/h	1.38	0.95-2.00	0.09
80km/h	1.51	0.78-2.92	0.22
90km/h and over	2.85	1.14-7.16	0.03
Distance to Closest Medical Facility			
< 5 kms	1.00	-	
5 - 9.99 kms	0.91	0.71-1.18	0.49
10 - 19.99 kms	0.81	0.60-1.11	0.19
20 kms and over	2.98	1.33-6.71	<0.01

[1] 'Other Diagnosis' includes injuries to multiple regions, injuries of unspecified body region, and non-injury diagnoses

The use of helmets were further analysed for the outcome of KSI, and adjusted for age, gender and whether a motor vehicle was involved in the accident (Table 38). Adjustment for involvement of a motor vehicle alone did not change the association between helmet wearing and KSI, however when additionally adjusted for age and gender, the OR of being KSI decreased from 0.71 to 0.61 for cyclists who did wear a helmet (OR: 0.61; 95% CI: 0.47-0.81; p<0.01).

Table 38: Multivariate analysis for helmet use, for the outcome of being KSI adjusted for motor vehicle involvement, age and gender, Sub-Cohort 2

Helmet Use	Univariate			Adjusted for MV involvement			Adjusted for MV involvement, age, gender		
	OR	95% CI	p-value	OR	95% CI	p-value	OR	95% CI	p-value
Worn	0.71	0.55-0.92	<0.01	0.70	0.54-0.91	0.01	0.61	0.47-0.81	<0.01
Unknown	0.54	0.39-0.75	<0.01	0.54	0.39-0.74	<0.01	0.49	0.35-0.68	<0.01
Not Worn	1.00	-		1.00	-		1.00	-	

Table 39 shows significant predictors of KSI using multivariate regression analysis for Sub-Cohort 2. This analysis included age group, gender, body region of injury, helmet use, Indigenous status, distance to medical facility, accident type, road alignment, speed limit, accident region, and motor vehicle involvement. The variables gender, Indigenous status, distance to medical facility, accident type, road alignment, road speed limit, accident region, and motor vehicle involvement were not found to be statistically significant and removed from the model.

Cyclists aged under 40 years were between 40-56% less likely to be KSI than cyclists aged 40-54 years, with cyclists aged 55 and over having the highest odds of all age groups of being KSI (OR: 1.10; 95% CI: 0.66-1.84). Injuries to the abdomen and head/neck region contributed to the highest risk of being KSI, being 6.8- and 5.9-times greater odds than upper limb injuries to result in being KSI respectively, when adjusted for other variables in the model. Cyclists who were reported to have worn a helmet were at lower odds of being KSI than cyclists who did not wear a helmet (OR: 0.53; 95% CI: 0.36-0.78).

There were no statistically significant interactions between variables in Sub-Cohort 2.

Table 39: Multivariate predictors of cycling injury for the outcome of being KSI, adjusted for all variables, Sub-Cohort 2[#]

Parameter	OR	95% CI	p-value
Age Group			
0-12	0.57	0.33-0.98	0.04
13-17	0.44	0.26-0.76	<0.01
18-39	0.60	0.38-0.93	0.02
40-54	1.00	-	
55+	1.10	0.66-1.84	0.71
Body Region of Injury			
Abdomen	6.83	3.86-12.08	<0.01
Head/Neck	5.88	3.54-9.75	<0.01
Upper Limb	1.00	-	
Lower Limb	1.76	1.00-3.12	0.05
Other Diagnosis*	6.93	3.05-15.73	<0.01
Helmet Use			
Worn	0.53	0.36-0.78	<0.01
Not Worn	1.00	-	
Unknown	0.43	0.27-0.70	<0.01

* ‘Other Diagnosis’ includes injuries to multiple regions, injuries of unspecified body region, and non-injury diagnoses

[#] The variables *gender, Indigenous status, distance to medical facility, speed limit, road alignment, motor vehicle involvement, accident type* and *accident region* were removed from the model at the p<0.1 significance level.

Chapter 5 Discussion

5.1 Chapter overview

The research undertaken for this thesis aimed to use linked data to (i) quantify cycling injury, (ii) characterise cycling injury, and (iii) determine risk factors to predict severe and fatal cycling injury in WA. This chapter discusses key findings in comparison to the current literature, presents the strengths and limitations of the study, and identifies implications for policy and practice with recommendations for future research directions.

5.2 Discussion of main findings

5.2.1 Quantification of cycling injury

There were 13,616 cases of cycling injury resulting in hospital admission or death in WA between 1995 and 2010, equating to an average of 851 cases per year. This number of cycling injuries is comparable to previous WA studies, when differences in exclusion/inclusion criteria applied in other studies are considered.[11, 163] However, figures in the current study are lower than those stated by Gavin[11] although the differences can be explained by variations in study methodology. Unlike the current study, Gavin[11] reported the number of hospital separations rather than the number of discrete injury events resulting from an accident, and hospital transfers and related readmissions were counted separately rather than part of the same continuous episode of care. Taking this into account, the results from Gavin[11] were expected to be higher than the current study for the years which overlap between the two studies (i.e. 1995-2000), and this expectation was confirmed with current findings. Similarly, the level of hospital admission in the current study is consistent with those reported by Ballestas[163] for the period 2000 to 2009. The statistically significant increase in cycling injury over time seen in this study also continues the trend observed by Gavin[11] for the years 1987 to 2000.

The rate of cycling injury leading to hospitalisation or death seen in the current study from 1995 to 2010 demonstrated a marginally increased injury rate, even when the size of the WA population was considered – indicating that the rise in the number of cycling crashes is due to factors other than just population growth.

Road safety strategies and policy planning in WA are based on statistics reported by the RSC, [69] therefore it is important to compare the findings from the current study to published RSC statistics. The RSC's annual publication 'Reported Road Crashes in WA' (RRCWA) reports the number of WA cycling crashes resulting in serious or fatal injury (defined as cyclists admitted to hospital or having died, i.e. KSI-RSC). The RRCWA primarily uses police-reported data, however secondary information is also sourced from the HMDC as an alternative data source, in recognition of differences in reporting reliability, and are reported separately. Comparisons can be made between the current study and the RRCWA publications as the cohort in the current study are essentially the cases that should ideally be captured by the KSI-RSC definition – as all cohort cases in the study population were confirmed to be admitted to hospital or have died within 30 days of the accident.[4]

When comparisons are made between the number of KSI-RSC cycling crashes reported in the RRCWA and the cases in the current study, the overall number of cycling injury cases observed in this study is substantially higher. For example, for the period of 2000 to 2010 the number of admitted and fatal injury in the current study was, on average, 8.6-times higher per year than the hospitalised and fatal injury figures recorded in the RRCWA crash data.[4, 232-234] The difference was as great as 11.6-times higher in 2000; 883 cases in the current study compared to 72 cases in the RRCWA data. This difference was expected, as these findings are in agreement with other studies which have described the considerable underreporting of cycling injury when using police-reported data only.[122, 131] Linked data findings have demonstrated that accident events for cyclists have a higher discordance rate between police and hospital data than that of other road users.[5, 14, 124, 130, 132] The reasoning behind the differences between RRCWA statistics and findings from the current study are discussed further in this chapter.

When comparing cycling injury from the current study to published RRCWA statistics sourced from the HMDC, the number of cycling accidents resulting in admitted or fatal injury reported in the current study were on average 2.5-times higher per year than the number of hospitalised accidents reported in the RRCWA.[4, 232-234] Although both the figures from this study and the RRCWA publications are sourced from the HMDC, the discrepancy in counts is due to the different criteria applied to identify incident cases. The RRCWA hospitalisation data apply a 12-month period to identify a new injury event, regardless of the form of injury, and if a patient's current hospital admission is more than 12 months since their previous hospital discharge, the current admission is considered to arise from a new accident. However, this criterion was applied to all road user groups, including car drivers, passengers and motorcyclists.[4] Such methodology is likely to underestimate the number of cycling injuries, as it is plausible for a cyclist to be admitted to hospital more than once within a 12-month period.[139] As described in Section 3.9.1.1, the current study applied a 28-day period to identify a new injury event. This 28-day criterion was specific to cyclists, and based on investigations of IRIS data where cyclists were known to have experienced more than one crash event. Furthermore, the methodology in the current study also takes diagnosis codes of injury into account for related hospitalisations within the 28-day period – an additional refinement to the RCS criteria to ensure the capture of multiple admissions relating to the same injury. The current study also includes fatal injuries that did not involve hospitalisation which is not included in the hospitalisation data used for RRCWA reporting.

Given the above findings, the use of linked hospitalisation and crash data should be considered in future RRCWA and state-wide reporting. The methodology used in the current study could be adopted to improve the accuracy of cyclist injury reporting, and guide further work necessary to develop specific methodologies for more accurate reporting of other road users, such as pedestrians. To persist with currently used methodologies would result in the continued underestimation of injured cyclists – it would be irresponsible not to utilise available enhanced information for a better understanding of this road user group to guide necessary policy development and improved road safety strategies.

5.2.2 Characteristics of cycling injury

5.2.2.1 Cyclist, injury and accident characteristics

Overall, the characteristics relating to cyclists, the injuries they sustained, and accident characteristics are consistent with previous WA, Australian and international cycling injury studies.

The findings here showed that cycling injury in WA was more common in children and occurred more often in males and the non-Indigenous population, indicating that injured cyclists in WA are demographically similar to those in other Australian states[137, 144, 165] and other Western countries.[127, 136, 188, 223, 235] The form of injury, and regions of the body injured were also similar to other interstate[165] and international populations.[118, 236, 237] As expected, characteristics of cyclists and associated injury were consistent with previous WA studies sourced from hospital admission data.[11, 12, 163]

For cases who were admitted to hospital, cyclists sustaining severe or fatal injury unsurprisingly had a longer average length of hospital stay than cyclists sustaining injuries of moderate severity, based on ICISS. Similarly, among injured cyclists who were admitted to the ICU, those who were KSI were at greater odds of having a longer stay in ICU than those who were not KSI. Although these findings suggest a relationship between length of hospital stay and injury severity, length of stay should only cautiously be used as a measure of injury severity, as length of stay can be influenced by factors independent of the injury, such as variations in hospital service delivery.[238]

Non-collision cycling accidents were the most common form of accident, of which most occurred off-road (73%), consistent with findings in other studies examining populations from sources other than police records.[8, 11, 12] The proportion of non-collision, on-road accidents (42% of all traffic accidents) was consistent with other studies which examined collision types among traffic accidents.[118, 239] However, it is worth considering that a non-collision accident does not necessarily indicate that another vehicle or object did not have a role in the accident, rather it only suggests that no direct collision occurred. It is possible that a cyclist was involved in a non-collision accident by taking evasive action to avoid a collision with another vehicle or object, and was injured as a result of a subsequent fall.

In examining trend data between the years 2000 and 2010, the number of non-traffic accidents among children decreased, however this has occurred in parallel with a sizable increase in traffic accidents among adults. These findings are likely reflective of the increase in the number of adults whose mode of transportation to work is cycling, as observed through Australian Census data,[76, 77] and is further supported by findings that peak hour traffic periods of 6am-9am and 3pm-6pm were the most likely time for accidents to occur. It has been suggested that reduced levels of childhood cycling could be attributed to reduced cycling to school,[79-81] possibly due to parental concerns regarding road safety and other factors over the last two decades.[240] This trend is concerning, given that declining active transport to and from school may reduce overall physical activity and have implications for childhood obesity and other health conditions.[34, 241] It is also possible that the reduction in levels of cycling in children may contribute to the reduced likelihood of continued cycling in adulthood.

The results of this study suggest that serious injury is more prevalent among cyclists who are not physically separated from other vehicles on carriageways, given that almost one-third of all accidents were found to occur on a public highway, street or road, and less than 4% of hospitalised and fatal injuries occurred on a sidewalk or cycle way. However, there may be irregularities in how place of occurrence has been recorded in the HMDC from information available to clinical coders, and hence caution should be taken in the interpretation of these findings when relying on hospital data. The high proportion of 'unspecified' codes reflects uncertainty in recording place of occurrence in hospital records, and it is difficult to determine the true error rate without an audit or validation of clinical coding, which was beyond the scope of this thesis. In addition, IRIS data also do not adequately capture this information and therefore this could not be validated for cases with a linked record. As a result, care should be taken when interpreting the place of occurrence findings in the context of cyclists and the sharing of roads with other road users.

Cycling accidents resulting in injury occurred mainly in metropolitan areas; most often involving the cyclist and one other vehicle, which was most often a motor vehicle. These results reflect findings from other studies.[12, 144, 166] In terms of vehicle movement, most WA cycling accidents resulting in injury were due to right-angle collisions, consistent with other Australian and international studies.[11, 105, 144, 235] The City of Mandurah had twice the number of KSI accidents of all other regional areas, and similarly the City of Stirling had nearly twice the number of KSI accidents relative to other metropolitan areas. However when the size of the population was taken into account, it was evident that the higher numbers observed in these LGAs were due to the size of the populations residing in these LGAs.

The City of Perth had the highest rate of KSI injury, which was more than double the rate of the Town of Victoria Park, the LGA with the next highest rate of KSI injury (8.9 cases and 3.9 cases per 100,000 population, respectively). As the City of Perth includes the Perth Central Business District, it is likely these findings are due to having a higher volume and density of cyclists and motor vehicles relative to other LGAs, and therefore greater opportunity for the two road user groups to interact.

Most metropolitan cycling accidents involved metropolitan residents, and similarly regional cycling accidents mostly involved regional residents. Where metropolitan residents were injured in regional accidents, and conversely where regional residents were injured in metropolitan accidents, the distances travelled between the accident site and residential address were large – in excess of 100 kilometres on average. However, these results should be interpreted with caution, as it cannot be determined if these distances were covered by the cyclist entirely by pedal cycle, or if the cyclist travelled (by means other than pedal cycle) to a different location before they were injured while cycling (e.g. metropolitan resident travelling to a regional location by car or aeroplane, then being subsequently injured while cycling in that regional area).

5.2.2.2 Characteristic differences between police-reported and non-police-reported cycling injury

The current study investigated the differences between cycling injury cases which were reported to police (i.e. had a linked IRIS record), versus cases which were not reported to police. Knowing that IRIS records are used primarily for state-wide reporting of cycling accidents, it was important to make comparisons between the police-reported cases and the non-police reported cases, which are currently not captured in state-wide reporting and therefore not currently considered in the development of road safety policy and strategies.

A number of studies have used linked data to specifically investigate cycling crash reporting rates,[122, 195] including studies from WA.[6, 12, 242] The results from this study indicate that over half the injuries arising from cycling accidents are non-traffic accidents. This would be one of the main reasons for the discrepancy between this study and the RSC statistics, as non-traffic crashes would be out of scope for mandatory police crash reporting. Although non-traffic accidents are not expected to be reported to police, this study has shown that there are still a substantial number of cycling accidents resulting in hospital admission or death which reportedly occur in traffic which are not captured in police crash records (36% of all records captured between July 1999 and December 2010, Table 21). This confirms observations from studies performed in WA,[5, 6, 11] Australia[243] and overseas.[131, 133] Rosman[244] found that only 14% of non-traffic accidents of all road user groups had a linked hospitalisation record. The findings from this study suggest that for cyclists, the linkage fraction for non-traffic could be as low as 1.1%.

Additionally, two-thirds of accidents were non-collision accidents; 86% of which were non-traffic accidents. The results here confirmed that non-collisions are not well reported to police. Given that it is mandatory to report accidents which result in property damage exceeding $3,000 ($1,000 up until July 2008), non-collision accidents are less likely to meet this criteria and thus be reported to police, particularly compared to accidents where a collision occurs with another vehicle. Non-collision accidents and non-traffic accidents are also less likely to be reported to police due to the lower likelihood of severe property damage or personal harm, this latter finding confirmed through multivariate analyses performed for the outcome of severe and fatal injury.

Furthermore, it was demonstrated that police-reported accidents were biased towards crashes of greater injury severity, and against single-vehicle non-collision crashes, and those that do not involve motor vehicles. Noting the findings which established that police were in attendance of 83% of accidents captured by IRIS, the relationship between the reporting of accidents to police and the factors of injury severity, motor vehicle involvement and police attendance, are intertwined. Cycling accidents involving motor vehicles are likely to be more severe and therefore be attended by police, resulting in greater likelihood of being captured in police reports. The overrepresentation of more severe cycling accidents in police-reported data may also be influenced by a general perception of cyclists that crashes only need to be reported when a motor vehicle or another party is involved. This may in part be due to insurance claim requirements, i.e., there is more incentive to report accidents involving a motor vehicle.[5] It is possible that there may be a lack of community knowledge that all accidents need to be reported if bodily injury and sufficient property damage occurs, regardless of the involvement of motor vehicles. This perception would explain why only the "most serious of serious" injury is routinely reported to police.

It is clear from the current findings that children are underrepresented among police-reported accidents; children comprise 37% of cases reported to police, however make up 62% of accidents which are not reported to police. This is consistent with previous work examining differences between police and inpatient data.[6, 12] This is most likely due to findings that children are less likely to be involved in traffic accidents, more likely to be involved in non-collision accidents which result in lower value damage, and children are less likely than adults to own pedal cycles of high monetary value. Findings of the current study also demonstrate that children sustain injuries less severe than adults – therefore are less likely to meet the criteria to qualify for mandatory police reporting. Although the number of child cycling injury accidents are declining, they still form a substantial portion of overall accidents which need to be considered in road safety strategies.

These findings are offset by the fact that not all accidents reported to police as requiring admission to hospital actually result in a hospitalisation, which blurs the definitions used in RSC publications. KSI-RSC is based on injury severity as recorded on the crash report, i.e., the person is considered KSI-RSC if they were admitted to hospital following the crash, or died. However as the crash report can be completed by either the attending police officer or self-reported, the validity of this measure is questionable. A person arriving at a hospital may not actually be admitted to hospital, rather they may only present to the emergency department for treatment and then be released home without requiring inpatient treatment. It is unclear whether such treatment has been reported as a 'hospital admission' in the IRIS data, and if so, the magnitude of such misreporting.

Two significant changes in road crash reporting in WA were expected to result in a noticeable reduction in reported cycling injury, however the expected changes were not observed in the current study. First, the increase in property damage value for mandatory police reporting of road crashes from $1,000 to $3,000 in July 2008 was expected to have resulted in only more severe crashes (at least in terms of property damage) reported from this date onwards, and subsequently a decrease in the number of cycling injury cases reported. Second, the introduction of the Online Crash Report Facility (OCRF) in 2009 changed the availability of police reports from the IRIS available for data linkage – since 2009 only police-attended crash records, and not the self-reported crash records, were available for linkage and subsequent analysis. This change was expected to result in less cases with linked IRIS data in 2009 and 2010 compared to earlier years. However the effects of these two changes were not apparent in this study, presumably due to the fact that the majority of cycling accidents are not well-reported to begin with, relative to accidents for other road user groups, and thus these changes had minimal impact on overall cycling crash reporting rates. Moreover, cycling crashes which were reported to the IRIS prior to the introduction of the OCRF were more likely to be of greater severity and hence attended to by police. Accidents of lesser severity are not well attended by police and more likely to be self-reported, if reported at all. Due to the low incidence of self-reported cycling crashes to police, the impact of the introduction of the OCRF is expected to be less for this study compared to studies investigating other road user groups where self-reported crashes are more common (e.g. motor vehicle crashes).

5.2.3 Predictors of injury

Multivariate analysis was carried out to examine the complex interplay of risk factors for injury severity. This analysis of all cycling injury cases demonstrated that the severity of cycling injury increased with age. Older age groups are more at risk of severe injury or death in road accidents, consistent with other cycling injury studies conducted internationally, [144, 231, 237, 245] and other injury severity studies performed in Australia.[246] This supports the reasoning that older cyclists are more vulnerable to severe injury due to increased fragility, slower reaction time and reduced physical health compared to cyclists of younger ages.[230, 247]

The involvement of motor vehicles in cycling accidents was significantly associated with injury severity when investigated in univariate analyses. However when analysed in a full multivariate model, when controlled for age, gender, body region of injury, accident type, motor vehicle involvement and presence of a linked IRIS record, this association was no longer significant. This is in contrast to findings from other studies which have examined injury severity that have performed multivariate modelling. However other studies have mostly sourced cases from police records[144, 231] which have been shown in the current study, and other studies,[5] to have a higher ascertainment of motor vehicle accidents than hospital data sources.

The complex nature of injury severity among injured cyclists is revealed through statistically significant interactions between age, body region of injury and the presence of a linked IRIS record. To the Candidate’s knowledge, these interactions have not been previously studied in the context of cycling injury. Body region increased the effect of age on being KSI, with injuries to the abdomen the most likely to result in cyclists being KSI. Bodily impact with bicycle handlebars is an injury common among cyclists, which can be a seemingly minor injury immediately after the accident, yet often results in delayed medical attention for a more serious underlying issue.[248] Cyclists who sustain injury resulting from direct impact of bicycle handlebars (which can include penetrating injury) have been associated with a higher likelihood of operative intervention and longer hospital stay, compared to cyclists who ‘flip over’ bicycle handlebars.[249] Few previous studies investigating the severity of cycling injuries have considered injuries to different body regions, as studies which have considered body region were specific in their analyses, namely for head injuries and often in the context of examining a particular intervention such as helmet use.[142]

The significant interaction between the presence of a linked IRIS record and age and body region indicated that cycling accidents which were reported to police were more severe for all age groups and for injuries to all body regions. This finding substantiates suggestions discussed above that severe cycling accidents are reported to police more often than those of lesser severity.[5]

Unlike the analysis of the full cohort, accident type and motor vehicle involvement were not statistically significant predictors of injury severity in regression analyses among cases reported to police. However, this would likely be due to the fact that all cases in this sub-cohort were traffic accidents, most of which involved motor vehicles. Age, body region of injury and helmet use were the only statistically significant variables arising from multivariate analyses, and no road factors were found to be significantly associated with level of injury severity. This is in contrast to other studies which have incorporated road factors in regression analysis, where factors such as road curvature, road speed limit and lighting conditions were associated with more severe injury[144]. However, it is worth noting that studies which have used police traffic sources have defined severe injury differently compared to the current study, with methods which were not derived from hospital clinical coding as per the current study through the calculation of the ICISS. Indicators of severe injury in other studies included transportation or admission to hospital,[144, 168] police-reported injury severity[245] or fatality.[231]

Findings relating to the use of helmets suggest that they have a protective effect for the risk of being KSI, similar to the existing body of literature investigating helmet use internationally[136, 180, 250] and in Australia.[251, 252] The increased odds of injury when a helmet was not worn was of similar magnitude to other studies.[180, 252, 253] Findings on paediatric road trauma by Mitchell[143] were consistent with the results of this study, and analyses of helmet use when adjusted for motor vehicle involvement align with findings by Bambach.[142]

5.3 Study strengths

5.3.1 Study design

The major strength of this research was the use of de-identified administrative whole-population-level health databases linked across three data collections; the HMDC, Death Registry and IRIS over a 16-year study period.

5.3.1.1 Data linkage

In Australian States other than WA, the use of linked datasets for road injury is a relatively new field, though the number of data linkage systems in Australia has grown in recent years.[254, 255] WA's well-established data linkage system allows inter-agency information to be examined, which permits a more comprehensive, system-wide approach to investigating population health issues, such as road injury.

Previous road injury studies have been limited due to available data – study populations sourced from police crash data have been limited by the lack of injury information;[144, 164] conversely, the use of hospitalisation data as a study population source have been limited by the lack of information regarding the crash which caused injury.[105, 119, 136, 137, 192] By combining data sources, important information from multiple sources can be gathered to present a more complete understanding of the accident circumstances resulting in injury or death, in addition to the nature and outcomes of the accident, to enable a holistic approach to injury prevention.

The use of linked data allows for the controlling of possible confounding variables sourced from data which have only been analysed together in regression models in few studies previously.[124, 143] While studies have previously linked data across hospital and police sources, most have only done so to describe data linkage rates and the comparability of data sources in terms of cycling injury.[12, 130, 243] Few studies have used linked data to gain insight into how police-reported accident characteristics relate to hospital-confirmed injury severity.[142, 143] The work in this study extends previous work investigating the use of linked data in road trauma by Watson[135] and injury severity work conducted in WA by Chapman[14] by specifically examining cycling injury, as opposed to all road user groups combined.

Previous studies using non-linked admitted hospital data have not accounted for hospital transfers and statistical admissions due to the inability to accurately link records belonging to the same person within a de-identified dataset; or failed to identify re-admissions as being related to the initial hospitalisation.[105, 163] By doing so, related subsequent care such as rehabilitative care are not considered, and length of stay calculations are potentially inaccurate.

In this study, the use of a unique patient identifier derived through data linkage enabled analysis of hospital episodes (comprising multiple separation records relating to the same injury event) rather than separations, facilitating better representation of the care received.

Using linked data sources also reduces the amount of multiple-counting across data collections giving a more accurate overall count and is less likely to artificially inflate the number of cycling injury cases at a population level. Despite this, the current study still found a higher incidence of cycling injury than most previous studies in this field, due to the improved methodology of identifying cycling injury cases through the use of linked data sources.

The provision of an encrypted patient identifier from the WADLB facilitated the analysis of de-identified population data, enabling the study of this state-wide cohort without compromising patient confidentiality. This is particularly important for the analysis of sensitive information, such as health and death records.

5.3.1.2 Use of longitudinal whole-population-level administrative data

As all cycling injuries resulting in hospitalisation or death which occur in WA have been captured in this study, the methodology applied to identify the study population in this study is supported by recommendations proposed by previous research.[5, 11] The use of all available state-wide inpatient and death data means that findings can be directly attributed to the WA population; including the longitudinal study of trends and health outcomes over time, examining associated factors, and also identifying vulnerable or at-risk sectors of the community. The use of whole-population-level administrative data also eliminates selection bias seen in other cycling studies using self-reported questionnaires,[119, 192, 195] and minimises known underreporting and self-reporting bias in crash data.[6, 12, 256]

The availability of longitudinal data for this study enabled the analysis of cycling injuries over a 16-year study period – equating to a larger study cohort which facilitated trend analysis over a greater period of time. The ability to perform trend analyses on a cohort derived from two linked datasets have improved upon other studies in this field, particularly in WA where previously only unlinked sources were used. Studies involving linked hospital and crash data in other Australian states have been limited to ten years or less.[142, 143]

Additionally, the use of longitudinal data allowed this study to identify cases who had multiple hospital admission records within 28 days, enabling the refinement of counting incident cases. It also enabled the differentiation of records among cases who had multiple cycling accidents over time, improving the accuracy of using hospitalisation data to identify cycling injury incidence.

5.3.2 Defining injury severity

An injury severity scoring system can be used by road safety strategists to better assess the impact of cycling injuries, rather than binary measures such as admission to hospital and/or fatality, as is used by the RSC.[4, 161] The use of ICISS in the current study has been demonstrated to be equal or superior to other injury severity scores such as the AIS and its derivatives such as the ISS.[147, 257] This has also been confirmed in previous WA studies examining the use of ICISS methodology in road injury studies.[14, 187]

Additionally, the linkage of hospital admission data with crash data has facilitated the application of ICD-based severity scaling methodology to police data. With a standardised ICD clinical coding structure, this method provides a platform where cross-jurisdictional and international comparisons for injury severity in police records can be made; reducing reliance on comparisons in research literature based on police- and self-reported injury severity.

5.3.3 Analysis methods

The study of geographical variations allows a system-wide approach where events can be examined within the context which they occur.[258] Thus, spatial analysis can be used to better understand the urban and rural environment in relation to injuries among vulnerable road user groups, as it allows for a wider range of risk factors to be considered. Studies of vulnerable road user groups using spatial analysis have involved identifying injury ‘hot spots’.[259] The current study has used geographical information from IRIS data to determine areas in WA with a higher occurrence of accidents. Additionally, it has applied this information in the context of injury severity, whereby spatial elements such as proximity to medical facilities can be considered in determining risk factors for serious or fatal cycling injury. The review of cycling injury research literature found that studies of cycling injury in relation to accessibility of medical treatment was limited – in the context of a jurisdiction as large as WA where limited services can have significant impact health outcomes, this analysis added a new dimension of investigating injury severity.

The availability of ample data from multiple sources, in terms of cohort size as well as data variables, provided the opportunity to perform multivariate analyses of adequate statistical power to identify even marginal shifts in outcomes investigated. This not only strengthened this study by reinforcing the advantages of using linked data, but enabled the analysis of more variables and interaction effects, with greater statistical precision, to provide valuable insight into other explanatory factors for the outcome of KSI.

5.4 Study limitations

5.4.1 Limitations of study datasets

Despite the breadth of data that can be obtained through the linkage of multiple datasets, the study population size with data available from all datasets will always be limited to the dataset with the least amount of data. This was apparent in this study where IRIS data was only available from 1995 to 2010 – data prior to 1995 and more recent than 2010 are not currently available for data linkage. Moreover, despite a study cohort sourced from HMDC and Death Registry of 13,616 cases, linking IRIS data to the cohort reduced the population available for the sub-analyses conducted for Aims 2 and 3 with accident data to only 10.1% (n=1,373) of the original cohort. Although data for more recent years were not available for study, this research has demonstrated the merits of using linked data methods in the field of road safety, and described methods which can be readily applied when more up to date data becomes available.

While date of admission was available, the lack of a specific 'Date of Injury' field in the HMDC was also a limitation. Previous Australian studies have explored this issue in the context of hospitalised injury because it limits injury rate calculations as the true numerator of crash events cannot be determined.[139, 260] However, the methodology employed in this study aimed to establish a process to address this issue in order to determine a more accurate method of quantifying cycling injury. The data analysis strategies used to determine the criteria utilised in the current study can be applied to determine more accurate numerator quantification in other road user groups.

The linkage of multiple administrative datasets brings together data collected under different criteria and reporting definitions, which can result in conflicting terminology. Accident type (traffic versus non-traffic) is a key example in this study; traffic accidents are described in ICD codes as "any vehicle accident occurring on the public highway (i.e. originating on, terminating on, or involving a vehicle partially on the highway)";[9] however this definition differs to that of the WA Police, where traffic crashes "occurred on a road or any place commonly used by the public, e.g. carparks".[261] Therefore the misalignment of definitions between data sources may contribute to discrepancies seen in this and other studies.

While the use of hospitalisation data for the identification of cyclist injuries shows greater potential than police data for capturing the true size of the problem, clinical coding constraints also contribute to the limitations of this study. Clinical coders are limited to only coding information that is documented by a clinician, and there is understandably little consistency across clinicians on cycling infrastructure terminology leading to potential misinterpretation (for example, interchangeable terms can include: cycleway, cycle path, bike lane, bike path, bikeway, cycle track, shared path, footpath or pavement).

In WA, crashes are reported either by a police officer attending a crash, or by a person involved in the crash – results from this study indicate that self-reported accidents account for 17% of cycling accidents. The completeness of IRIS data has room for improvement, as a large number of variables collected have missing or unknown values, which limited the analysis in this study – for example, helmet usage was not recorded in 23% of cyclists with IRIS data in this study. With the implementation of the OCRF there is potential to improve the completeness of the data through the online system, with electronic prompts and mandatory responses required before allowing the user to proceed with submitting their crash report. Self-reported data also limits the validity and accuracy of the IRIS data – recall bias may occur where a report is submitted by a person involved in the crash. Items such as helmet use may be subject to further reporting bias among self-reported data to conform to social expectations or, as it is illegal for cyclists aged over 12 years old to cycle without a helmet, compliance with legislative requirements in WA.

5.4.2 Lack of data on extent of cycling

To calculate meaningful and relevant injury rate statistics, two measures are needed: (i) the number of injuries, and (ii) comparable exposure information. Two measures of cycling exposure are commonly used: (i) distance/time travelled by cyclists, and (ii) population of cyclists per capita. Without this information, it is not possible to accurately determine if cycling-related hospitalisations and deaths are increasing, decreasing or remaining stable, relative to cycling participation. Whether cyclists are occasional, regular or frequent cyclists also affects their exposure to the risk of cycling injury,[262] and thus this information should be considered where possible, although this information is not available from administratively collected data in WA.

For a population-based study using administrative data, it is not possible to determine the cumulative distance or time travelled for all trips individual cyclists take, or the number of cycling activities participated in, for every injured cyclist to measure a cyclist's exposure to the risk of cycling injury. The true number of cyclists in WA is not known, and can only be estimated through surveys, cycling counters and Census data.[74, 75, 83, 85] Similar approaches have also been used previous studies.[6, 141] Therefore, population data can only be used as a proxy, until more accurate exposure information can be adequately captured.

5.5 Implications of main findings

The issue of cycling safety concerns both injury prevention and road safety interest groups, which are key groups influencing policy and legislation. There are ongoing discussions in WA regarding changes to legislation to improve the safety of cyclists, such as the adoption of a one-metre minimum distance law for drivers when overtaking cyclists.[263] In April 2016, legislation was amended to allow cyclists to cycle on footpaths.[264] The cycling strategies and policies and large investments by both State and Federal government authorities demonstrate the strong commitment to develop a safer cycling environment, which will lead to more sustainable and liveable cities for the future. In this context, the need for accurate information to aid effective decision making is needed more than ever before.

This study has confirmed that the under-reporting of hospital admitted and fatal cycling injuries to police in WA is considerable. As such, it is apparent that road safety authorities have only focussed on the ‘tip of the iceberg’ when it comes to cycling injury; a substantial proportion of accidents which result in hospitalisation which are not police reported are being overlooked. With the introduction of WA’s Mountain Bike Strategy encouraging more off-road cycling, among other cycling strategies, non-traffic accidents which are not traditionally captured by police reports are only expected to rise.

Unlike other road users such as motor vehicle drivers and motorcyclists, no registration or legal requirements are required to participate in cycling, and therefore, the WA cycling population is a difficult group to characterise. From both an injury prevention and road safety perspective, the importance of having a better understanding of the nature and size of cycling injury cannot be overstated, particularly in relation to the following four reasons:

1. *Implications for the way cycling injury is perceived*: This study demonstrates that the problem of cycling injury in WA is much greater than previously realised. The realisation of the true size of the problem, and the factors causing injury, have the potential to influence the way this health and road safety issue is addressed by road safety authorities and injury prevention groups. The findings that cycling injury in children, non-collisions, and non-traffic accidents are not well represented in traditional crash statistics indicate that current road safety measures and policies may not be adequately addressing the needs of all those involved in such accidents.

2. *Implications for the perception of cycling safety*: Describing the full extent of cycling injury has the potential to alarm and scare potential future cyclists. Conversely, it arms road safety and cycling advocates with the necessary facts to promote a safer cycling

environment, improve road safety education and enable authorities to enforce greater measures to protect cyclists. The better characterisation of injured cyclists facilitates enhanced road safety campaigns and strategies targeted at key groups at risk of cycling injury. Through strategies to protect cyclists, and better education of road users, positive measures to encourage cycling will attract more cyclists in years to come.

3. *Implications for the burden of cycling injury*: For an individual, serious injuries can result in short-term or long-term disability, psychological effects, reduced productivity and decreased quality of life. It can also place significant burden on the families of the injured person, particularly if the injury results in loss of income for the household, and additional care giving is required. At a population level, the burden of injury likely induces significant healthcare and resourcing costs. Considering that much of the burden of mortality and morbidity from road traffic crashes is preventable, it is possible to be reduced if addressed appropriately.

4. *Implications for the targeting of road safety campaigns and cycling promotion:* The results of the regression analysis in this study have highlighted key groups of cyclists who are at greater risk of serious injury than other cyclists. These findings will aid road safety groups to develop road safety and awareness campaigns targeted to specific cyclist groups and other relevant road users, resulting in a more efficient and effective use of resources.

5.6 Future directions

There is enormous potential in data linkage studies, particularly in the field of road injury research which is yet to realise the maximum potential of linked data, especially in WA where data linkage infrastructure is well established. Studies have investigated the feasibility of utilising data linkage techniques in other Australian jurisdictions such as Queensland, which have demonstrated that this is a method which holds much promise.[135] This study has sought to explore the use of linked data while also providing an overview of cycling injury in WA. Each cyclist, injury and accident characteristic explored in this study has the potential to be explored in greater depth and detail.

5.6.1 Evolving cycling landscape

Several initiatives have recently been implemented in WA which are aimed at protecting cyclists by physically separating them from motor vehicles, including (i) changes to legislation to allow cyclists of all ages to cycle on footpaths,[264] and (ii) the introduction of 'bicycle boulevards'; dedicated roads where pedal cycles are given priority over motor vehicles.[107] While the findings from the current study suggest that police-reported accidents involving motor vehicles may not be significantly associated with being KSI, further research needs to be undertaken which incorporates all police-reported cycling accidents in order to fully examine this association for the WA population. Furthermore, allowing people to cycle on footpaths means that cyclists will share paths with pedestrians, and levels of injury between cyclists and pedestrians should not be discounted. Where this study has demonstrated underreporting of cycling injury, it is likely that other vulnerable road users such as pedestrians are similarly underreported. A linked data analysis of pedestrian accidents based on the methodology used in this study would enable analysis into the possible similar rates of underreporting of pedestrian injury, and more detailed cyclist-pedestrian analyses could further evaluate the effect of this change in legislation. Further, similar analyses can be performed for all road user groups, which would facilitate comparisons between all road users to determine relative risks of injury.

5.6.2 Incorporation of additional data

The cohort for this study was based on cyclist injury or death occurring between 1995 and 2010, as this was the maximum year range for which data were available across all three data sources at the time of data application. The continuing expansion of data linkage capabilities in WA means that more datasets across a greater number of years may be linked in the future to create a richer resource that provides more comprehensive data on injured cyclists, enabling a wide range of research projects that can be undertaken.

By expanding the scope of the cohort to include cyclists with a crash record but without a hospitalisation or death record, there is potential to make further comparisons between cyclists with severe versus less severe injury. It would be expected that a significant portion of these cases would have an ED record. Although data from the DOH Emergency Department Data Collection (EDDC) have been available for linkage since 2002 they were not included in this study due to specific limitations of the data collection. Unlike the HMDC data, the EDDC data do not record external cause of injury codes that are based on the ICD coding system through a standardised clinical coding mechanism, making it difficult to reliably identify if a patient presenting to an ED was a cyclist in a manner consistent with the cohort data sourced from the HMDC and Death Registry for this study.[265] Processes are being developed to improve the quality of coded information collected through the EDDC, which will potentially enable the accurate capture of cyclists who present to ED immediately after the crash has occurred – the key piece of information missing in the piecing together of a cyclist's injury 'story'. It is expected that the number of cyclists with injuries presenting to ED who are not admitted to hospital for inpatient stay are likely to be substantial, further amplifying the level of cyclist injury that is not currently captured or considered in strategies employed to ensure safer roads. Additionally, the inclusion of ED data, in combination with HMDC data, would potentially allow for the validation of police-reported injury severity.

Data from the State Trauma Registry were also considered for use in this study, to provide more in-depth investigation of characteristics of severe and fatal injuries and provide additional information not captured in other data sources, including the use of helmets. However at the time of data application, linked data for this data collection were not complete across the state, as it was only available for one of the five WA hospitals which are part of the State Trauma Registry. Data for all hospitals in the State Trauma Registry Database became available for data linkage in 2015.[199]

5.6.3 Cycling infrastructure studies

The spatial analysis conducted in this study is only the beginning of exploring the severity of cycling injuries in relation to environmental factors. Given that there may be inaccuracies in the place of accident occurrence codes based on the hospitalisation record, cycle network data available from the Department of Transport could potentially be used to examine cycle path and on-road bike path usage among injured cyclists. Accidents occurring on the road reserve are the accidents over which road safety regulatory authorities have the greatest influence. Given recent legislative changes to allow people to cycle on footpaths, and previous studies suggesting there is significant risk of injury when cycling on footpaths,[8, 105, 266] further exploration of patterns of injury in relation to location and road infrastructure would be worthwhile.

5.6.4 Burden of cycling injury

There is potential to conduct further analysis of linked data to quantify the burden of cycling injuries in WA. As the ICISS is a ‘threat-to-life’ indicator of injury, it does not consider the broader impacts of injury – such as the economic cost of cycling injuries to society, disability resulting from injury, and years of potential years of life lost in the case of fatalities. However, there are other means of conducting such analyses, facilitated by the use of linked data. Economic analyses can be performed, and if EDDC and HMDC data were linked, it would possible to determine the total cost of cycling injury to the health system, from a cyclist’s presentation to an ED through to hospital discharge. The impact of such injuries could be examined at a population level in terms of disability-adjusted life years. Further, the impact of premature mortality in fatal cases could also be calculated by the years of life lost due to cycling accidents.

Chapter 6 Conclusion

Cycling offers many benefits to individuals and the community, for health, economic, environmental and urban sustainability reasons. It is clear why authorities are keen to encourage cycling uptake through the implementation of various strategies and policies, and invest significant funds and resources to improve cycling accessibility and safety to facilitate increased participation. The perception of safety of cycling as an activity is a significant factor in influencing cycling uptake, as non-cyclists are less likely to participate in an activity which is perceived to be dangerous or risky. However, a clear understanding of cycling injury, and the factors contributing to it, are key to determining the difference between perceived risk and actual risk.

This study has shown that the use of only road traffic crash data to report state-wide cycling injury statistics is insufficient for capturing the true size of the problem. Other sources such as hospital and death records need to be considered to realise the full extent of cycling injury in WA, which could be up to nearly 12-times higher than currently reported statistics. Although the rate of cycling injury relative to the size of the population has only marginally increased, the number of actual cases and therefore number of individuals affected by preventable injury and subsequent absolute burden on health services is on the rise.

The current study has also shown that cases of cycling injury where cyclists are adults, the injury sustained is of greater severity, and accidents which involve collisions with motor vehicles are overrepresented in police-reported statistics. However, non-collision accidents and accidents in children make up a substantial proportion of overall cycling injury cases in WA, which are not being included in RSC reported road injury statistics. It is therefore highly likely that the needs of these 'invisible' groups are not being adequately considered in road safety and injury prevention programs. In a field where changes to legislation are being made with the aim of improving safety, it is important such significant decisions are not made based only cases which make up the 'tip of the iceberg', and that all affected parties are considered, ideally with decisions based on robust empirical evidence.

Watson[138] has previously described six core characteristics of data sources which should be considered when determining appropriateness for use in injury studies: relevance, completeness, accuracy, consistency, timeliness and accessibility; and how data linkage can overcome limitations in data to improve data utilised in road injury studies. For purposes of measuring and reducing cycling injury in WA, data relevance in this study relates to whether the adequately data represents the WA population, and if the data and findings are useful to the end-users of the information, which include government authorities who evaluate rates of injury to drive policy to reduce road trauma. The current use of police-reported statistics do not meet these needs, as the KSI-RSC definition does not include all cases it purports to capture (i.e., all cycling accidents involving admission to hospital and/or death). This is addressed in this study through the linking of hospital admission and death data. Data linkage also improves issues of data completeness by identifying relevant cases from multiple data collections, while also enabling the analysis of crash information through the linkage to IRIS data; the breadth of information available through the linkage of multiple datasets dramatically enhances data completeness. The accuracy of measuring injury severity in this study has improved on other road injury studies[14, 105, 143] by using ICISS sourced from linked hospital separations and death data, and linked to crash data – this method provides crash records with an injury severity measure which is less reliant on police-based measures which are prone to misclassification, and additionally provides a measure which indicates a threat-to-life, rather than just an outcome of whether a patient was hospitalised or not. In terms of data consistency, the use of standardised clinical coding classifications by qualified staff ensured that cycling injuries are consistently captured over time, which is critical to longitudinal studies. While timeliness of the data could be improved due to the unavailability of more recent available data for linkage, the fact that the data linkage infrastructure and processes are already established means that once the data become available, the linked data will be readily accessible.

This study has extended previous work in WA, Australia and internationally on cycling injury, not only by updating previous knowledge in a contemporary setting to address current-day needs, but also by providing more in-depth information and longitudinal perspectives of cycling injury through detailed use of linked data. The current study has examined the 'person, place and time' of cycling injury – the three core elements of modern day descriptive epidemiology.[267] This was achieved by using hospital admission, death and crash data to investigate factors relating to cyclists and their injuries; examination of the geographic and road environment of accidents resulting in injuries, in addition to the spatial elements of the issue; and considering temporal factors while also longitudinally studying the issue over a 16 year period.

The examination of the characteristics of injury, and predictors of severe and fatal injury in the current study have determined risk factors for cycling injury for the WA population. The elucidation of these factors provides policy makers and strategists with improved knowledge which will support targeted intervention programs to reduce severe and fatal injury in the WA community. Findings which associate the lack of helmet use with a higher odds of being KSI support helmet legislation in WA.

The methodology adopted in this study has the potential to be used in routine state-wide road statistics reporting. As it is based solely on administrative data, the information is readily accessible and the capabilities for linkage are already present through the WA DLB. The techniques utilised can also be adapted to examine other road user groups, such as pedestrians and motor cyclists. Furthermore, this study has provided an example of cross-agency data linkage which can be used beyond the realms of academic research – there is great potential for the advantages of data linkage to be harnessed by agencies for business-oriented investigation and reporting, particularly where linkages already exist.

Further analysis of injuries which did not involve hospital admission or fatality should be considered in future work where possible to determine the complete risk of all forms of injury. While the current study has highlighted factors contributing to severe and fatal injury, injuries of a more moderate to minor nature need to also be considered so that risks of minor versus severe injury can be evaluated and the whole picture of cycling injury at a population level over time can be observed.

In conclusion, this study has addressed the question of whether current cycling injury statistics used to guide strategies to improve road safety in cyclists are sufficient. Not only has this study demonstrated that the current practice of using only police-reported data for this purpose is inadequate, it has established a robust methodology which combines linked data methods and injury severity measures which can be readily adopted for future study of cycling injury, which can also be adapted for the investigation of similar research in among other road user groups. In doing so, this study has enabled the examination of the interplay between cyclist, injury and accident characteristics with injury severity, and provided insight for the better understanding of factors which contribute to cycling injuries leading to hospitalisation and fatality in WA. This research broadens existing local, national and international knowledge, and has laid the foundation to improve strategies and policies for road safety not only among cyclists, but also other road users in WA.

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Appendices

Appendix A: Hospital Inpatient Summary Form

Appendix B: Medical Cause of Death Certificate

Appendix C: Report of Road Traffic Crash Form (P72)

Appendix D: List of variables received from WA Data Linkage Branch

Appendix E: Map of Western Australian Local Government Authorities

Appendix F: Map of Western Australian Local Government Authorities – Metropolitan

Appendix G: Injured cyclists – residence by LGA

Appendix A: Hospital Inpatient Summary Form (HA22)

HOSPITAL INPATIENT SUMMARY FORM (HA22)

July 2014
(New values: ***bold & italics*****)**

Account/Adm. No.

Episode of Care Link Field

Client Identifier (URN)

Mother's Identifier (URN)
(Baby's form only)

d d m m y y y y h h : m m

Admission Date/Time

d d m m y y y y h h : m m

Separation Date/Time

(Hospital) Establishment

Surname

First Forename

Second Forename

Residential Address (No./Street)

(Suburb)

State/ Territory of Residence

Postcode

Medicare Number

Medicare Person No

d d m m y y y y

D.O.B.

Sex
1. Male 2. Female 3. Indeterminate

Indigenous Status
1. Aboriginal not TSI 2. TSI not Aboriginal
3. Aboriginal and TSI 4. Other

Marital Status
1. Never Married 2. Widow 3. Divorced
4. Separated 5. Married/Defacto
6. Unknown/Not Stated

Employment Status
1. Child not at School 2. Student
3. Employed 4. Unemployed 5. Home Duties
6. Retired 7. Pensioner 8. Other

Interpreter Service 1. Yes 2. No

Language

Country/State of Birth

Admitted From (Establishment)

Source of Referral-Location
1. Home 2. Residential Aged Care Service
3. Other Health Care Accommodation
4. Acute Hospital 5. Psychiatric Hospital
6. Prison 7. Other

Source of Referral-Professional
1. Gen. Practitioner 2. Specialist Clinician
3. Outpatient Dept. Clinician 4. Emergency Dept. Clinician 5. Hospital Clinician (Readmission)
6. Community Health Clinician
7. Statistical Admission/Type Change 8. Other

Source of Referral-Transport
1. Private/Public Transport 2. Hospital – Patient Transport 3. Ambulance – Emergency
4. Royal Flying Doctor Service 5. Helicopter
6. Other

Intended Length of Stay
1. Intended Same-Day Stay
2. Intended Overnight Stay

Accommodation Occupied
1. Single Room 2. Shared Room

Ward/Location

Specialty of Clinician On Admission

Clinician on Admission (MBRN)

Admission Status
3. Elective – Waitlist
4. Elective – Not Waitlist
6. Emergency – Emergency Department Admission
7. Emergency – Direct Admission

Readmission Status 1.Planned 2.Unplanned

Unplanned Return to Theatre 1.Yes 2.No

Infant Weight / Neonate (Grams)

Funding Source for Hospital Patient
21. Australian Health Care Agreements
22. Private Health Insurance
23. Self-Funded 24. Worker's Compensation
25. Motor Vehicle Third Party Personal Claim
26. Other Compensation 27. DVA
28. Department of Defence 29. Correctional Facility
30. Reciprocal Health Care Agreements
31. Ineligible 32. Other
33. Ambulatory Surgery Initiative 34. Detainee

Insurance Status (Health) 1. Yes 2. No

Veterans Card Colour 1. Gold 2. White

DVA File Number

Care Type
21. Acute Care
22. Rehabilitation Care (Subacute)
23. Palliation Care (Subacute)
24. Psychogeriatric Care (Subacute)
25. Maintenance Care (Non-Acute)
26. Newborn 27. Organ Procurement 28. Boarder
29. Geriatric Evaluation and Management (Subacute)
30. Aged Care 31. Flexible Care (MPS sites only)

Client Status
0. Funding Hospital 1. Qualified Newborn
2. Unqualified Newborn 3. Boarder
4. Nursing Home Type 5. Contracted Service
6. Admitted Client 7. Organ Procurement
8. Resident

Contracted / Funding Establishment

Total Leave Days

Number of Leave Periods

Days of Psychiatric Care

Mental Health Legal Status
1. Involuntary 2. Voluntary

Days of Qualified Newborn Care

Hours in ICU (Whole Hours)

Hours CVS (Whole Hours)

Days of Hospital in the Home Care

Discharged To (Establishment)

Mode of Separation
1. Transfer to Acute Hospital
2. Transfer to Residential Aged Care Service
3. Transfer to Psychiatric Hospital
4. Transfer to Other Health Care Accommodation
5. Statistical Type Change
6. Left Against Medical Advice
7. Discharge from Leave
8. Deceased
9. Other/Home

Specialty of Clinician On Separation

Clinician on Separation (MBRN)

CLINICAL DETAILS
(Using Australian Coding Standards)

Principal Diagnosis **Cond. Onset Flag**

Co-Diagnosis (Code Also) **Cond. Onset Flag**

Additional Diagnoses
And related codes - Including Morphology, External Cause, Place of Occurrence and Activity codes

ICD-10-AM Code COF ICD-10-AM Code COF

ACHI Code d d m m y y y y Clinician (MBRN)

Principal Procedure

Additional Procedure(s)

Doctor's Name

Coder ID

Appendix B: Medical Certificate of Cause of Death

BDM 202

Registry of Births, Deaths & Marriages Western Australia

MEDICAL CERTIFICATE OF CAUSE OF DEATH

Details of Deceased (PLEASE PRINT CLEARLY IN BLOCK LETTERS)

Surname	
Given names (in full)	
Sex	Male ☐ Female ☐ **Date of death** / /
Place of death (in full)	
Age at death	(show age in completed units - Y= years or M = months)
Aboriginal or Torres Strait Islander origin?	(If of both Aboriginal and Torres Strait Islander origin, cross both "Yes" boxes) No ☐ Yes, Aboriginal origin ☐ Yes, Torres Strait Islander origin ☐
Date last seen alive by me	/ /
Coroner	Is this death being, or has it been, reported to the Coroner? No ☐ Yes ☐
Post mortem status	Not to be conducted ☐ Has been conducted ☐ Yet to be conducted ☐

Cause of Death Details

		Cause	Approximate interval between onset & death
Part I Disease or condition directly leading to death*	(a)	due to	

*This means the disease, injury or complication which caused death – **not only** the mode of dying, such as heart failure, respiratory failure etc.

		Cause	Approximate interval between onset & death
Antecedent causes (b) - (e)	(b)	due to	
Morbid conditions, if any, giving rise to the above cause (a), **stating the underlying condition last**	(c)	due to	
	(d)	due to	
	(e)		
Part II Other significant conditions contr[illegible]g to death but not related to the disease or condition causing it			

Other Details

Operations	Was an operation performed on the deceased within 4 weeks of death?	No ☐	Yes ☐ (if "Yes" specify below)
Type of operation			
Disease/condition			
Pregnancy	Was the deceased pregnant within 6 weeks of death?	No ☐	Yes ☐
	Was the deceased pregnant between 6 weeks and 12 months of death?	No ☐	Yes ☐
Injury	Was an injury/external cause involved in the death?	No ☐	Yes ☐ (if "Yes" specify below)
	Only complete if death is not reportable to the Coroner		

Certification

I hereby certify that I am a currently registered medical practitioner and that:

- I was responsible for the medical care of the abovenamed deceased immediately before death AND/OR
- I examined the body of the abovenamed deceased after death

and that the particulars and cause of death above written are true to the best of my knowledge and belief. This certificate is signed pursuant to Section 44 (1) of the Births, Deaths and Marriages Registration Act 1998.

Full name	Phone
Address	
Signature	Date / /

Appendix C: Report of Road Traffic Crash Form (P72)

WESTERN AUSTRALIA POLICE **P72**

REPORT OF ROAD TRAFFIC CRASH

THERE IS NO COMPULSION TO REPORT A TRAFFIC CRASH IF:

- **Damage to ALL VEHICLES and/or PROPERTY is LESS than $3000, and**
- **There is NO INJURY TO ANY PERSON involved in this crash, and**
- **The PROPERTY OWNER has been advised of your details, and**
- **The crash is NOT a Hit and Run crash**

Local No.
Crash No.

Please print clearly. Please enter as many details as possible. Where more than two parties involved - use an additional form.

1) *POLICE USE ONLY* ☐ **POLICE CRASH** **OFFICER ON DUTY (Y/N)……….**

Police Officer attending scene: Name…………………………PD No. …………… Sub District/Unit…………………………

Crash attended at: (time)……………(date)………………………… Police Crash (Y/ N)…… Photographs (Y/N)……. Scene Marked (Y/N)………

DRIVER 1 – Prelim. *POS / NEG* BAC **0.**____CALC TO **0.**__ __ __ **DRIVER 2** – Prelim. *POS / NEG* BAC **0.** __ __ __CALC TO **0.** __ __ __

Blood test taken (Y/N)…… Driver Number…… **Contributing factors** - Excessive Speed (Yes / No) / Fatigue (Yes / No) / Inattention (Yes / No) / Unknown

2) PRECISE LOCATION OF CRASH

NAME OF SUBURB, TOWN OR LOCALITY…………………………………………POSTCODE…………

A) OCCURRED AT THE INTERSECTION OF…………………………………………

AND…………………………………………

OR

B) ON…………………………… ……… Metres N / S / E / W OF…………………………………

(street and or public area crash occurred on) …………Kilometres (nearest cross street, landmark etc)

AREA SPEED ZONE ………………KPH

3) DAY OF CRASH ☐ Sunday ☐ Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐ Saturday

TIME OF CRASH __ __ __ __ 24 hours

DATE OF CRASH ………/………/………

4) HIT AND RUN (Y/N)……. Driver (M/F)……. Estimated age……… Description of Driver ……………………………………

Description of Vehicle (include any accessories fitted to vehicle)……………………………………

NUMBER OF VEHICLES INVOLVED IN CRASH - __ __

5) INVOLVED VEHICLE 1 – YOUR Details SEATBELT WORN (Y/N) …… PURPOSE OF TRAVEL: PRIVATE / BUSINESS

DRIVER'S FAMILY NAME……………………………GIVEN NAMES…………………………… SEX: (M/F) ……

ADDRESS……………………………………………SUBURB……………………………POSTCODE…………

OCCUPATION……………………………………EMPLOYER……………………………………

PHONE No.: Work……………………Home……………………Mobile…………………… DATE OF BIRTH………/………/…….

DRIVERS LICENCE: No…………………… STATE OF ISSUE………………… LICENCE CLASS/ES………………

LICENCE TYPE (Ordinary, Probationary, Learner, Expired, Cancelled etc.)…………………………… EXPIRY DATE………/………/……

VEHICLE MAKE AND MODEL…………………………… COLOUR………………… BODY TYPE………………………

HEAVY VEHICLES: Configuration No:………… (see page 4 for ID number) Was it Loaded (Yes/No)…… Type of load ……………………

REGISTRATION No……………………STATE OF REGISTRATION…………EXPIRY DATE………/………/………No. OF OCCUPANTS __ __

OWNERS NAME…………………………… ADDRESS……………………………………

OWNERS INSURANCE COMPANY…………………… DESCRIPTION OF DAMAGE……………………………………

VEHICLE TOWED (Y/N) …… POLICE AUTHORITY (Y/N)…… TOWING COMPANY……………………………………

WHERE TOWED ……………………………………………………………

6) INVOLVED VEHICLE 2 SEATBELT WORN (Y/N) …… PURPOSE OF TRAVEL: PRIVATE / BUSINESS

DRIVER'S FAMILY NAME……………………………GIVEN NAMES…………………………… SEX: (M/F) ……

ADDRESS……………………………………………SUBURB……………………………POSTCODE…………

OCCUPATION……………………………………EMPLOYER……………………………………

PHONE No.: Work……………………Home……………………Mobile…………………… DATE OF BIRTH………/………/…….

DRIVERS LICENCE: No…………………… STATE OF ISSUE………………… LICENCE CLASS/ES………………

LICENCE TYPE (Ordinary, Probationary, Learner, Expired, Cancelled etc.)…………………………… EXPIRY DATE………/………/……

VEHICLE MAKE AND MODEL…………………………… COLOUR………………… BODY TYPE………………………

HEAVY VEHICLES: Configuration No :…………(see page 4 for ID number)… Was it Loaded (Yes/No)…… Type of load……………………

REGISTRATION No……………………STATE OF REGISTRATION…………EXPIRY DATE………/………/………No. OF OCCUPANTS __ __

OWNERS NAME…………………………… ADDRESS……………………………………

OWNERS INSURANCE COMPANY…………………… DESCRIPTION OF DAMAGE……………………………………

VEHICLE TOWED (Y/N) …… POLICE AUTHORITY (Y/N)…… TOWING COMPANY……………………………………

WHERE TOWED ……………………………………………………………

7) INJURIES AND ALL PERSONS IN YOUR VEHICLE: – refer to KEY below when completing involved persons details:

KEY: Include one of the following for Position	PERSON	INJURY	SEATBELT/HELMET	AIRBAG
Seating position: 9 6 3 / 8 5 2 / 7 4 1 10. Back of the vehicle/wagon 11. Towed device 12. Bus seat 13. On tray (utility/truck) 14. Riding externally on vehicle 99. Unknown For M/C or Cyclist use 1 and 4	1. Driver / Rider 2. Passenger 3. Pedestrian	1. Killed 4. Admitted to hospital as inpatient 2. Injured, medical treatment only 5. Injured, no medical treatment 6. No injury	1. Worn 2. Not worn 3. Child restraint worn 4. Child restraint not worn 5. Unknown	1. Deployed 2. Fitted not deployed 3. Not fitted

INJURIES AND ALL INVOLVED PERSONS : (include drivers) Enter full details for each person. (Your vehicle is vehicle No 1)	Veh No	Seating Position	Person	Injury	Seatbelt / Helmet	AIRBAG
1 NAME:						
ADDRESS			Date of Birth / /			
2 NAME:						
ADDRESS			Date of Birth / /			
3 NAME:						
ADDRESS			Date of Birth / /			
4 NAME:						
ADDRESS			Date of Birth / /			
5 NAME:						
ADDRESS			Date of Birth / /			
6 NAME:						
ADDRESS			Date of Birth / /			
7 NAME:						
ADDRESS			Date of Birth / /			
8 NAME:						
ADDRESS			Date of Birth / /			

CRASH FEATURES (Cross all appropriate boxes)

8) TRAFFIC CONTROL
- ☐ 1. Traffic Lights
- ☐ 2. Stop Sign
- ☐ 3. Give Way Sign
- ☐ 4. Pedestrian Crossing
- ☐ 5. School Crossing
- ☐ 6. No Sign or Control
- ☐ 7. Other – specify:

.....………………….

Rail Level Crossing
- ☐ 8. Boom Gates
- ☐ 9. Flashing Lights Only
- ☐ 10. Stop Sign
- ☐ 11. Give Way
- ☐ 12. Unguarded

9) ROAD FEATURE
- ☐ 1. 4 Way intersection (crossroads)
- ☐ 2. 3 Way Junction / T Junction
- ☐ 3. Multiple intersection
- ☐ 4. Roundabout
- ☐ 5. Median opening
- ☐ 6. Slow Point (eg. speed hump)
- ☐ 7. Railway crossing
- ☐ 8. Bridge
- ☐ 9. Subway
- ☐ 10. Driveway
- ☐ 11. Pedestrian Island
- ☐ 12. No special feature
- ☐ 13. Other – specify:

……………………………

10) ROAD ALIGNMENT
- ☐ 1. Left Curve ☐ 2. Right Curve
- ☐ 3. Straight

12) ROAD GRADE
- ☐ 1. Level
- ☐ 2. Crest of Hill
- ☐ 3. Up Slope ☐ 4. Down Slope

14) ATMOSPHERIC CONDITIONS
- ☐ 1. Clear
- ☐ 2. Fog / mist
- ☐ 3. Raining
- ☐ 4. Smoke, dust
- ☐ 5. Overcast
- ☐ 6. Sun Glare
- ☐ 7. Other – ……………………………………………………………

11) ROAD CONDITION
- ☐ 1. Wet
- ☐ 2. Dry

13) ROAD SURFACE
- ☐ 1. Sealed
- ☐ 2. Unsealed
- ☐ 3. Off road

15) LIGHTING
- ☐ 1. Daylight
- ☐ 2. Dawn or Dusk

Darkness
- ☐ 3. Street lights on
- ☐ 4. Street lights off
- ☐ 5. Street lights not provided

16) ESTIMATE of combined damage of ALL vehicles AND property: Less than $3000 ☐ Over $3000 ☐

17) Type of Crash (Cross all appropriate boxes)

(1) Vehicle to Vehicle Collisions
- ☐ 1. Right turn into oncoming vehicle
- ☐ 2. Right angle collision
- ☐ 3. Side impact - same direction
- ☐ 4. Side impact - opposite direction
- ☐ 5. Head on collision
- ☐ 6. Rear end collision
- ☐ 7. Collision with parked vehicle
- ☐ 8. Collision with one vehicle reversing

(2) Single Vehicle Collision

On Road OR **Off Road**
- ☐ 1. Struck pedestrian
- ☐ 2. Struck animal
- ☐ 3. Struck object
- ☐ 4. Overturned
- ☐ 5. Fall from moving vehicle
- ☐ 6. Struck pedestrian
- ☐ 7. Struck animal
- ☐ 8. Struck object
- ☐ 9. Overturned
- ☐ 10. Fall from moving vehicle

If you hit an object, state each object and distance of each object from the road……………metres

3 Vehicle Movement Prior to Crash (Select appropriate vehicle numbers and enter into boxes, e.g. V 1, V 2 or V3

A Direction	Veh	B Lane	Veh		Veh	C Approach	Veh
1 North bound		1 1st lane (kerb or left)		5 Left turn lane		1 Approaching intersection	
2 South bound		2 2nd lane		6 Merge lane		2 Within intersection	
3 East bound		3 3rd lane		7 Shoulder		3 Not related with intersection	
4 West bound		4 Right turn lane		8 On wrong side of road		4 Into driveway	
						5 Out of driveway	

D Action	Veh		Veh	E Other	Veh		Veh
1 Straight ahead		5 Overtaking right side		1 Proceeding normally		4 Out of control	
2 Right turn		6 Overtaking left side		2 Slowing		5 Changing lanes	
3 Left turn		7 Backing		3 Stopped		6 Turn - Into parking	
4 U-turn		8 Parked				7 Turn - Out of parking	

18) INDEPENDENT Witnesses (Not Passengers)		Telephone Number		
NAME	ADDRESS	Work	Home	Mobile

19) DESCRIPTION and DETAILS of CRASH - Briefly describe how the crash happened, **stating clearly speeds of vehicles before and at impact: if vehicle lights on, if vehicle fitted with roo bar/bull bar, and if Ambulance attended.**

1. What colour were the Traffic Control Lights (Red / Amber / Green) facing: **you** ………………………
2. How far were you from the vehicle / pedestrian when you first sighted them / it……………………………
3. Did you sound your horn (Y/N) ………………………

20) Sketch of Locality

Label all vehicles and objects

1. Show street names
2. Show control signs, road markings
3. Show all objects struck and by which vehicle
4. Select appropriate symbols for diagram
5. Show **NORTH** point

PEDESTRIAN

VEHICLE 1 [1> (front)

VEHICLE 2 [2> (front)

21) Number of sheets used to report this crash:………

I understand and acknowledge that this form may be adduced in evidence in any court proceedings resulting from the investigation of this crash. Information may be released in accordance with the Western Australia Police Service Privacy Statement.

Please retain a copy of this form as it may be required by your Insurance Company and/or Solicitor. ***Costs apply for additional copies.***

22) ***ONLY SIGN AT TIME FORM IS HANDED TO RECEIVING OFFICER***

Signature……………………………… Time…………24 Hours Date ……/……/……

Police / Staff Signature……………………………… Print Surname ……………………………… PD No………………

Sub District / Unit……………………………… A/L………………………………

For self-reported crashes only

Copy provided ☐**Yes** ☐**No** - Reason if No………………………………

WESTERN AUSTRALIA POLICE SERVICE P72 – ADDITIONAL VEHICLES

`6a) INVOLVED VEHICLE 3 SEATBELT WORN (Y/N) …… PURPOSE OF TRAVEL: PRIVATE / BUSINESS

DRIVER'S FAMILY NAME…………………………………………GIVEN NAMES…………………………………………………… SEX: (M/F) …….

ADDRESS……………………………………………………………………………SUBURB…………………………………POSTCODE…………..

OCCUPATION……………………………………………………EMPLOYER……………………………………………………………….

PHONE No.: Work……………………….Home……………………………Mobile……………………………… DATE OF BIRTH………/………/……..

DRIVERS LICENCE: No………………………………STATE OF ISSUE……………………LICENCE CLASS/ES……………………………

LICENCE TYPE (Ordinary, Probationary, Learner, Expired, Cancelled etc.)……………………………………………… EXPIRY DATE………/………/……..

VEHICLE MAKE AND MODEL……………………………………………… COLOUR…………………… BODY TYPE…………………………………

HEAVY VEHICLES: Configuration……………………………………………Was it Loaded (Yes/No)…… Type of load ……………………………………

REGISTRATION No…………………………STATE OF REGISTRATION…………EXPIRY DATE………/………/………No. OF OCCUPANTS ___

OWNERS NAME…………………………………………… ADDRESS…………………………………………………………………………

OWNERS INSURANCE COMPANY………………………… DESCRIPTION OF DAMAGE…………………………………………………………

VEHICLE TOWED (Y/N) …… POLICE AUTHORITY (Y/N)…… TOWING COMPANY…………………………………………………………

WHERE TOWED ……

6b) INVOLVED VEHICLE 4 SEATBELT WORN (Y/N) …… PURPOSE OF TRAVEL: PRIVATE / BUSINESS

DRIVER'S FAMILY NAME…………………………………………GIVEN NAMES…………………………………………………… SEX: (M/F) …….

ADDRESS……………………………………………………………………………SUBURB…………………………………POSTCODE…………..

OCCUPATION……………………………………………………EMPLOYER……………………………………………………………….

PHONE No.: Work……………………….Home……………………………Mobile……………………………… DATE OF BIRTH………/………/……..

DRIVERS LICENCE: No………………………………STATE OF ISSUE……………………LICENCE CLASS/ES……………………………

LICENCE TYPE (Ordinary, Probationary, Learner, Expired, Cancelled etc.)……………………………………………… EXPIRY DATE………/………/……..

VEHICLE MAKE AND MODEL……………………………………………… COLOUR…………………… BODY TYPE…………………………………

HEAVY VEHICLES: Configuration……………………………………………Was it Loaded (Yes/No)…… Type of load ……………………………………

REGISTRATION No…………………………STATE OF REGISTRATION…………EXPIRY DATE………/………/………No. OF OCCUPANTS ___

OWNERS NAME…………………………………………… ADDRESS…………………………………………………………………………

OWNERS INSURANCE COMPANY………………………… DESCRIPTION OF DAMAGE…………………………………………………………

VEHICLE TOWED (Y/N) …… POLICE AUTHORITY (Y/N)…… TOWING COMPANY…………………………………………………………

WHERE TOWED ……

6c) INVOLVED VEHICLE 5 SEATBELT WORN (Y/N) …… PURPOSE OF TRAVEL: PRIVATE / BUSINESS

DRIVER'S FAMILY NAME…………………………………………GIVEN NAMES…………………………………………………… SEX: (M/F) …….

ADDRESS……………………………………………………………………………SUBURB…………………………………POSTCODE…………..

OCCUPATION……………………………………………………EMPLOYER……………………………………………………………….

PHONE No.: Work……………………….Home……………………………Mobile……………………………… DATE OF BIRTH………/………/……..

DRIVERS LICENCE: No………………………………STATE OF ISSUE……………………LICENCE CLASS/ES……………………………

LICENCE TYPE (Ordinary, Probationary, Learner, Expired, Cancelled etc.)……………………………………………… EXPIRY DATE………/………/……..

VEHICLE MAKE AND MODEL……………………………………………… COLOUR…………………… BODY TYPE…………………………………

HEAVY VEHICLES: Configuration……………………………………………Was it Loaded (Yes/No)…… Type of load ……………………………………

REGISTRATION No…………………………STATE OF REGISTRATION…………EXPIRY DATE………/………/………No. OF OCCUPANTS ___

OWNERS NAME…………………………………………… ADDRESS…………………………………………………………………………

OWNERS INSURANCE COMPANY………………………… DESCRIPTION OF DAMAGE…………………………………………………………

VEHICLE TOWED (Y/N) …… POLICE AUTHORITY (Y/N)…… TOWING COMPANY…………………………………………………………

WHERE TOWED ……

6d) INVOLVED VEHICLE 6 SEATBELT WORN (Y/N) …… PURPOSE OF TRAVEL: PRIVATE / BUSINESS

DRIVER'S FAMILY NAME…………………………………………GIVEN NAMES…………………………………………………… SEX: (M/F) …….

ADDRESS……………………………………………………………………………SUBURB…………………………………POSTCODE…………..

OCCUPATION……………………………………………………EMPLOYER……………………………………………………………….

PHONE No.: Work……………………….Home……………………………Mobile……………………………… DATE OF BIRTH………/………/……..

DRIVERS LICENCE: No………………………………STATE OF ISSUE……………………LICENCE CLASS/ES……………………………

LICENCE TYPE (Ordinary, Probationary, Learner, Expired, Cancelled etc.)……………………………………………… EXPIRY DATE………/………/……..

VEHICLE MAKE AND MODEL……………………………………………… COLOUR…………………… BODY TYPE…………………………………

HEAVY VEHICLES: Configuration……………………………………………Was it Loaded (Yes/No)…… Type of load ……………………………………

REGISTRATION No…………………………STATE OF REGISTRATION…………EXPIRY DATE………/………/………No. OF OCCUPANTS ___

OWNERS NAME…………………………………………… ADDRESS…………………………………………………………………………

OWNERS INSURANCE COMPANY………………………… DESCRIPTION OF DAMAGE…………………………………………………………

VEHICLE TOWED (Y/N) …… POLICE AUTHORITY (Y/N)…… TOWING COMPANY…………………………………………………………

WHERE TOWED ……

Appendix D: List of Variables Received from the WA Data Linkage Branch

<u>Hospital Morbidity Data Collection</u>
Data Custodian: Paul Stevens
Source: Inpatient Data Collections, Data Integrity Directorate, WA Department of Health

Age at admission
Gender
Indigenous Status
Hospital category
Length of stay
Source of referral – transport
Admission Status
Care Type
Days in ICU
Mode of separation
Principal diagnosis code
Co-diagnosis code
Additional diagnosis codes
External cause of injury codes
Activity code
Place of occurrence code
Admission Date
Separation Date
Latitude of Residential Address at Admission
Longitude of Residential Address at Admission
Injury Survival Risk Ratios

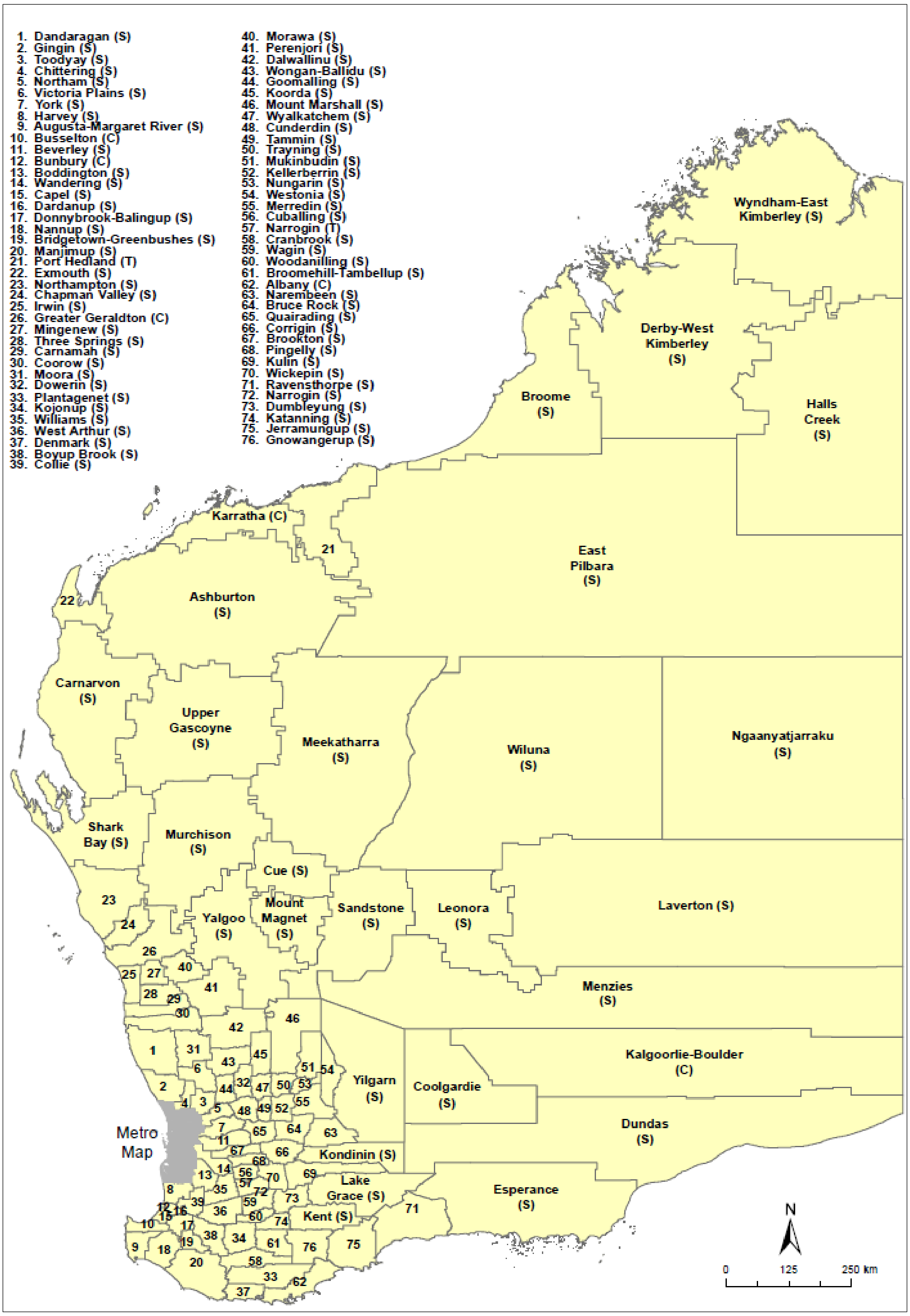
<u>Death Registry</u>
Data Custodian: Di Rosman
Source: Data Linkage Branch, for the Registry of Births, Deaths and Marriages

Registration Year
Sex
Died in hospital flag
Age
ATI status
Date of death 1
Date of death 2
Date of death code
Cause of death code (ABS)
Entity Axis data
Record axis data
Place of occurrence code (ABS)
Activity code (ABS)
Cause of death text
Latitude of Residential Address at Death
Longitude of Residential
Address at Death

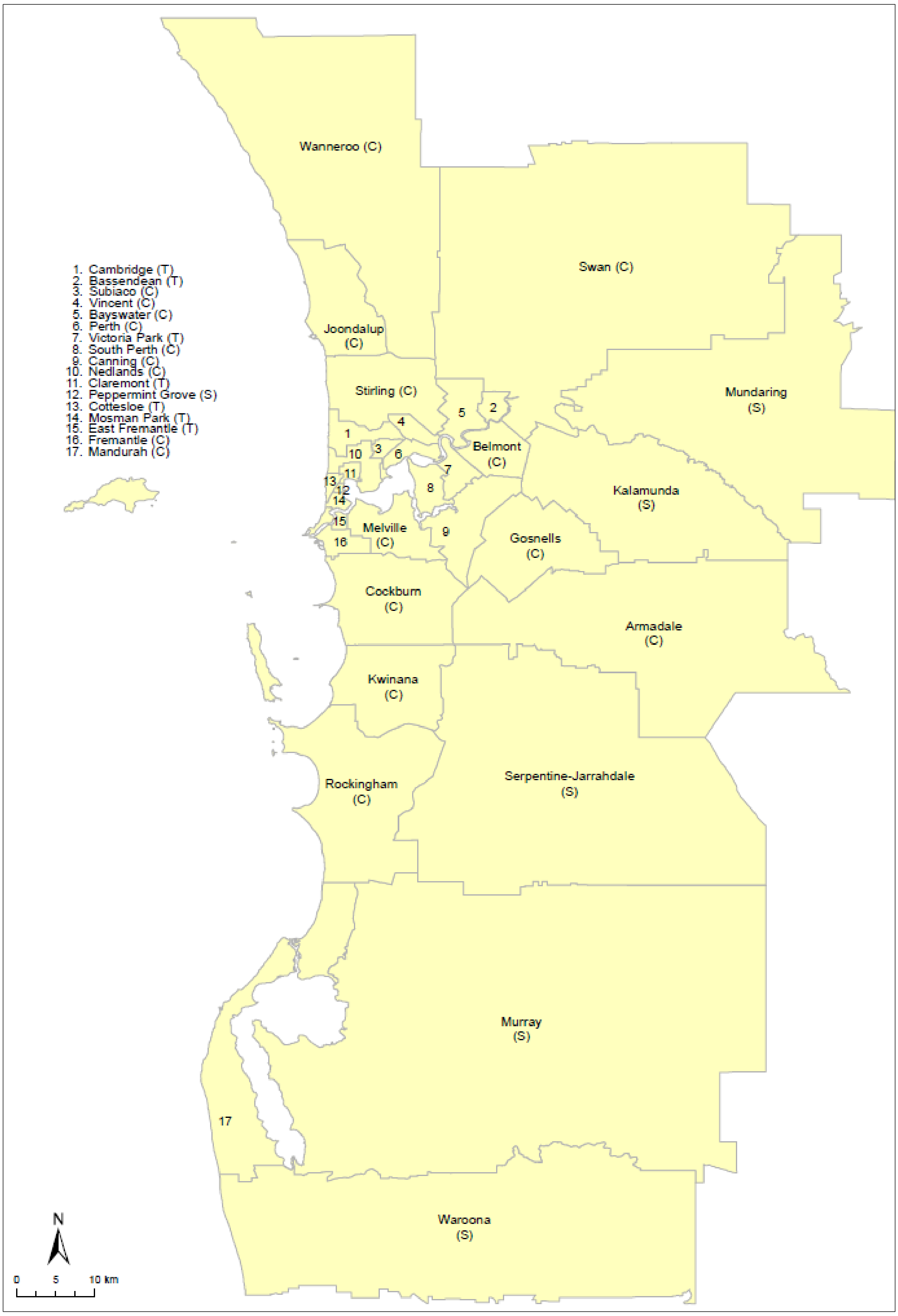
<u>Integrated Road Information System</u>
Data Custodian: Anthony Maroni
Source: Main Roads WA

Accident ID
Unit Number
Person Number
Event ID
Road User Type
Police Attended
Sex
Age
Injury
Accident Severity
Protection Worn
Accident Date
Longitude of crash site
Latitude of crash site
Day of Week
Time
Atmospheric Condition
Lighting
Unit Type
Body Type
Roo or Bull Bar
Was it loaded
Type of Load
Traffic Control
Traffic Control Functioning
Road Feature
Road Alignment
Road Grade
Road Condition
Road Surface
Road Works Site
Speed Factor
Speed Limit
Post Code
Accident Scope
Accident Type
Inattention
Fatigue
Final Alcohol Reading
Intersection Description
Straight Line Kilometre
Road Name
Carriageway
First Cross Road Name
Second Cross Road Name
Road User Movement
MR Type Code
Non Collision Code
Event Location Code
Colliding Unit Movement
Colliding Unit Origin Direction
Colliding Unit Destination Direction
Target Unit Movement
Target Unit Pedestrian Movement
Target Unit Impact Point
Target Unit Origin Direction
Target Unit Destination Direction
First Object Hit
Second Object Hit
Third Object Hit
MR Nature Code

Appendix E: Map of Western Australian Local Government Authorities



Appendix F: Map of Western Australian Local Government Authorities - Metropolitan



Appendix G: Injured cyclists – residence by LGA

Residential Region	LGA Name	n
Metropolitan	CITY OF STIRLING	1055
	CITY OF JOONDALUP	1042
	CITY OF GOSNELLS	646
	CITY OF MELVILLE	617
	CITY OF WANNEROO	590
	CITY OF SWAN	584
	CITY OF ROCKINGHAM	546
	CITY OF CANNING	501
	CITY OF ARMADALE	472
	CITY OF COCKBURN	406
	SHIRE OF KALAMUNDA	396
	CITY OF BAYSWATER	309
	SHIRE OF MUNDARING	302
	CITY OF BELMONT	237
	CITY OF SOUTH PERTH	229
	CITY OF VINCENT	196
	CITY OF FREMANTLE	191
	TOWN OF CAMBRIDGE	182
	TOWN OF VICTORIA PARK	172
	CITY OF NEDLANDS	143
	CITY OF KWINANA	138
	CITY OF SUBIACO	123
	TOWN OF BASSENDEAN	102
	CITY OF PERTH	66
	TOWN OF COTTESLOE	63
	TOWN OF MOSMAN PARK	55
	TOWN OF CLAREMONT	53
	TOWN OF EAST FREMANTLE	43
	SHIRE OF PEPPERMINT GROVE	15
Regional	CITY OF MANDURAH	371
	CITY OF BUNBURY	263
	CITY OF ALBANY	220
	CITY OF KALGOORLIE-BOULDER	198
	CITY OF BUSSELTON	192
	CITY OF GREATER GERALDTON	165
	SHIRE OF ROEBOURNE	141
	SHIRE OF HARVEY	136
	SHIRE OF SERPENTINE-JARRAHDALE	111
	SHIRE OF AUGUSTA-MARGARET RIVER	105
	SHIRE OF BROOME	104
	SHIRE OF COLLIE	102

Residential Region	LGA Name	n
Regional (continued)	SHIRE OF ESPERANCE	92
	SHIRE OF MANJIMUP	83
	SHIRE OF EAST PILBARA	72
	SHIRE OF NORTHAM	68
	SHIRE OF CAPEL	65
	SHIRE OF WYNDHAM-EAST KIMBERLEY	64
	TOWN OF PORT HEDLAND	63
	SHIRE OF ASHBURTON	63
	SHIRE OF DARDANUP	58
	SHIRE OF MURRAY	54
	SHIRE OF KATANNING	40
	SHIRE OF DERBY-WEST KIMBERLEY	40
	TOWN OF NARROGIN	38
	SHIRE OF CARNARVON	34
	SHIRE OF DENMARK	30
	SHIRE OF COOLGARDIE	28
	SHIRE OF MERREDIN	26
	SHIRE OF BRIDGETOWN-GREENBUSHES	23
	SHIRE OF DONNYBROOK-BALINGUP	20
	SHIRE OF MOORA	20
	SHIRE OF HALLS CREEK	19
	SHIRE OF EXMOUTH	19
	SHIRE OF TOODYAY	17
	SHIRE OF YORK	16
	SHIRE OF IRWIN	15
	SHIRE OF DANDARAGAN	15
	SHIRE OF LEONORA	14
	SHIRE OF NORTHAMPTON	14
	SHIRE OF PLANTAGENET	14
	SHIRE OF CHITTERING	13
	SHIRE OF GINGIN	13
	SHIRE OF YILGARN	13
	SHIRE OF DUNDAS	12
	SHIRE OF WAROONA	12
	SHIRE OF NANNUP	12
	SHIRE OF KELLERBERRIN	11
	SHIRE OF BOYUP BROOK	11
	SHIRE OF GNOWANGERUP	10
	SHIRE OF MEEKATHARRA	10
	SHIRE OF BEVERLEY	10
	SHIRE OF CUNDERDIN	9
	SHIRE OF COOROW	9
	SHIRE OF RAVENSTHORPE	9
	SHIRE OF WONGAN-BALLIDU	9
	SHIRE OF QUAIRADING	8

Residential Region	LGA Name	n
Regional (continued)	SHIRE OF BODDINGTON	8
	SHIRE OF DALWALLINU	8
	SHIRE OF LAKE GRACE	7
	SHIRE OF PINGELLY	7
	SHIRE OF WAGIN	7
	SHIRE OF LAVERTON	6
	SHIRE OF CUBALLING	6
	SHIRE OF CORRIGIN	6
	SHIRE OF NAREMBEEN	5
	SHIRE OF KOJONUP	5
	SHIRE OF NGAANYATJARRAKU	5
	SHIRE OF KENT	5
	SHIRE OF KONDININ	<5
	SHIRE OF GOOMALLING	<5
	SHIRE OF WILUNA	<5
	SHIRE OF VICTORIA PLAINS	<5
	SHIRE OF WILLIAMS	<5
	SHIRE OF MUKINBUDIN	<5
	SHIRE OF BRUCE ROCK	<5
	SHIRE OF CHAPMAN VALLEY	<5
	SHIRE OF CRANBROOK	<5
	SHIRE OF DUMBLEYUNG	<5
	SHIRE OF KOORDA	<5
	SHIRE OF TAMMIN	<5
	SHIRE OF KULIN	<5
	SHIRE OF THREE SPRINGS	<5
	SHIRE OF BROOMEHILL-TAMBELLUP	<5
	SHIRE OF WICKEPIN	<5
	SHIRE OF JERRAMUNGUP	<5
	SHIRE OF MINGENEW	<5
	SHIRE OF WYALKATCHEM	<5
	SHIRE OF NUNGARIN	<5
	SHIRE OF WESTONIA	<5
	SHIRE OF BROOKTON	<5
	SHIRE OF WANDERING	<5
	SHIRE OF WOODANILLING	<5
	SHIRE OF YALGOO	<5
	SHIRE OF MENZIES	<5
	SHIRE OF MOUNT MAGNET	<5
	SHIRE OF MORAWA	<5
	SHIRE OF TRAYNING	<5
	SHIRE OF WEST ARTHUR	<5
Unknown		8
Total		13021

For patient confidentiality reasons, counts less than five and associated percentages are not published (‘n.p.’)