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Centre for Accident Research & Road Safety - Queensland (CARRS-Q)

Monograph 5

Bicycle Helmet Research

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The Centre was created to address the enormous human, economic and social costs resulting from road crashes. It has expanded its research scope to include the broader area of injury prevention with a particular interest in youth and risk-taking behaviours. Its charter is to identify, assess and initiate innovative priority-driven research and teaching programs leading to the development and implementation of strategies to improve safety on our roads, in our workplaces and in our communities.

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Monograph 5

Centre for Accident Research & Road Safety - Queensland (CARRS-Q)

Document Retrieval Information

Document no.	CARRS-Q Monograph Series - Monograph 5
Date	November 2010
Pages	60
ISBN	978 0 9751596 8 2
Title	Bicycle Helmet Research
Published by	Centre for Accident Research & Road Safety - Queensland, (CARRS-Q) Queensland University of Technology Victoria Park Road Kelvin Grove Q 4059 Australia

Abstract

Recent research on bicycle helmets and concerns about how public bicycle hire schemes will function in the context of compulsory helmet wearing laws have drawn media attention. This monograph presents the results of research commissioned by the Queensland Department of Transport and Main Roads to review the national and international literature regarding the health outcomes of cycling and bicycle helmets and examine crash and hospital data. It also includes critical examinations of the methodology used by Voukelatos and Rissel (2010), and estimates the likely effects of possible segmented approaches to bicycle helmet wearing legislation.

The research concludes that current bicycle helmet wearing rates are halving the number of head injuries experienced by Queensland cyclists. Helmet wearing legislation discouraged people from cycling when it was first introduced but there is little evidence that it continues to do so. Cycling has significant health benefits and should be encouraged in ways that reduce the risk of the most serious injuries. Infrastructure and speed management approaches to improving the safety of cycling should be undertaken as part of a Safe System approach, but protection of the individual by simple and cost-effective methods such as bicycle helmets should also be part of an overall package of measures.

Keywords

Bicycle, helmets, legislation, regulation, injuries

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1. CARRS-Q research and activity reports are disseminated in the interests of information exchange.
2. The views expressed are those of the author(s) and do not necessarily represent those of the Centre for Accident Research & Road Safety - Queensland.

This document should be cited as:

Haworth, N., Schramm, A., King, M., Steinhardt, D. (2010). **Bicycle Helmet Research.** (CARRS-Q Monograph 5). Brisbane, Australia: QUT, CARRS-Q

ISBN Number: 978 0 9751596 8 2

Printed in Australia

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EXECUTIVE SUMMARY

Recent research on bicycle helmets and concerns about how public bicycle hire schemes will function in the context of compulsory helmet wearing laws have drawn media attention. The Queensland Department of Transport and Main Roads (TMR) has commissioned the Centre for Accident Research and Road Safety – Queensland (CARRS-Q) to review the available research and data to inform the development of the policy paper.

This report commences with reviews of the national and international literature regarding the health outcomes of cycling and bicycle helmets and then presents crash and hospital data. The report also includes critical examinations of the methodology used by Voukelatos and Rissel (2010), and possible segmented approaches to bicycle helmet wearing legislation.

Cycling and health outcomes

The effects of bicycle riding on health can be positive or negative and can be divided into those which are direct to the individual and indirect effects on society as a whole. Elvik (2000) notes that the net effect on health of walking and cycling to the individual is the outcome of three impacts: (i) exposure to the risk of road crashes, (ii) exposure to air pollution from walking or cycling close to motor vehicles, and (iii) walking and cycling as a form of physical exercise. Indirect benefits may accrue to society if increased cycling results in less car use and therefore reductions in air pollution.

Approximately 70% of Australians undertake insufficient weekly levels of physical activity which is associated with a number of chronic health conditions. A 10km bicycle commute to work twice a day has been shown to improve fitness and HDL cholesterol levels. The annual health benefit of active travel by bicycle has been estimated at approximately $3,500 for each new person, and half that value for continuing commuters (Genter et al 2008).

A large number of studies have sought to examine the relationship between physical inactivity and increased mortality and morbidity. Some studies have focussed on cycling, while others have included a range of different types of physical activities. The research has generally found that cycling (and other forms of physical activity) are associated with lower premature mortality, cardiovascular disease, cancer (all, colon, breast and lung), Type 2 diabetes, and depression. However, there are many factors that affect both health and the likelihood of cycling, making unambiguous links between cycling and better health outcomes difficult.

Research into exposure to air pollution has shown that cyclists inhale more pollutants than drivers because of increased breathing rates and that this can result in immediate and longer-term cardiopulmonary damage. However, the general conclusion of most of this research has been that the benefits of physical activity outweigh the negative effects of exposure to air pollution (Pearce et al., 1998, cited in Elvik, 2000).

The public health argument for bicycle use is a strong one, but includes a number of assumptions that can be questioned and the comparisons with injury data suffer from the poor quality and completeness of cycling injury data. There is a need to use the same basis of costing for both disease and injury costs, because injury costs are sometimes underestimated by using the human capital approach. The lower and upper threshold values for exercise (including cycling) to have a health benefit require good population data on how many people are riding how far and for how long and what other exercise they are doing that is generally missing. While safety in numbers has become something of a mantra, the underlying principles at the individual (cyclist and driver), local and wider level need to be understood. The initial demonstration of safety in numbers showed that increases in walking and cycling were found to lead to lower risk to the individual, but an increase in total motor vehicle crashes involving pedestrians and cyclists was still predicted. Some more recent research has examined whether circumstances could exist in which the reduction to risk to the individual could be large enough to result in an overall reduction in crashes.

Cycling fatality and injury rates vary considerably among countries, being lowest in countries with well-developed cycling infrastructure and high cycling participation. While Australian rates per kilometre travelled are not available, New Zealand estimates show that fatality rates for cyclists per hour of travel are about four times greater than for car travel. In countries with low cycling participation (such as Australia but without universal helmet laws) the fatality rate per distance travelled is about 14 to 28 times higher than travelling in a car, although estimates of distances travelled by bicycle may not be reliable. Injury rates are more difficult to estimate because many low severity injuries are not treated and many on-road crashes are not reported to Police.

Off-road riding is associated with lower injury severities than riding on the road. Clearly-marked, bicycle-specific facilities (including cycle tracks at roundabouts, bike routes, bike lanes and bike paths) are safer than on-road cycling with traffic or off-road with pedestrians and other users. Bicycle crashes on rural roads are often more serious because of the higher average vehicle speeds and lack of bicycle infrastructure.

Bicycle helmets

A review of the most scientifically rigorous research concluded that bicycle helmets that meet national standards protect against head, brain, and facial injuries. Helmet wearing was associated with a 69% reduction in the likelihood of head or brain injury and a 74% reduction in the likelihood of severe brain injury. The benefit was the same whether a motor vehicle was involved in the crash or not. Helmet wearing reduced the likelihood of injury to the upper and mid-face by 65%.

In Australia, bicycle helmet wearing laws are universal in approach, applying to bicycle riders and pillions of all ages who are riding on roads and road-related areas (except in Northern Territory where they apply only on roads). Road-related areas include most riding locations. Bicycle helmet wearing laws have been introduced in many other jurisdictions in North America and Europe but most commonly apply only to children (or apply to certain riding areas only in a small number of countries).

Compulsory helmet laws have been criticised by various organisations (e.g. the British Medical Association) and individuals. Many of these critics acknowledge the injury reductions associated with helmet wearing but consider that these are outweighed by detrimental health and safety impacts associated with reductions in cycling participation. Others have argued that helmets encourage risky riding or that they distract attention from other safety measures such as improvements to infrastructure and reductions in motor vehicle speeds.

The introduction of bicycle helmet wearing legislation has led to increases in wearing rates in jurisdictions where the legislation is universal (with lower rates but still increased for teenagers) and where it applies to children only.

Australian and international research has demonstrated that introduction of bicycle helmet legislation was followed by a reduction in the number and severity of head injuries to cyclists. New Zealand research shows that the legislation has good cost-effectiveness. In support of this conclusion, changes to US motorcycle helmet laws have shown that head injury (and overall fatality and injury) rates have increased when universal laws were repealed and returned to earlier levels when laws were reinstated.

The ability to assess the effects of bicycle helmet laws on cycling participation rates is constrained by the lack of long-term participation data that covers all types of riding. It is also difficult to predict what current cycling participation levels might have been under different scenarios.

Limited work has been conducted in Australia specifically to evaluate the effect of helmet legislation on cycling participation. In Melbourne adult cyclist numbers doubled after the helmet legislation was introduced but there were fewer child cyclists, particularly teenagers. Data from South East Queensland suggests that the number of journeys to work by bicycle fell after the introduction of helmet legislation but now exceeds pre-legislation trip numbers. However, this excludes the number of trips taken by for purposes other than commuting (recreation, social, health and fitness, training etc.) which are likely to outnumber commuting trips.

Research studies, bicycle counts, sales data and anecdotal evidence suggest that cycling is increasing in popularity. There is evidence that the number of commuter cyclists has increased in Melbourne since 2006, and that the total number of cyclists travelling on bicycle paths in Perth increased between 2008 and 2010.

The WAVE surveys undertaken in Queensland provide little reliable information on the extent to which compulsory helmet wearing is a disincentive to cycling because of the very small number asked this question and the variations in how the question has been asked over time. Even among the small sample of respondents, compulsory helmet wearing was never provided as an unprompted response and it was the sixth or tenth most common response when prompted. Other Australian surveys have also reported that compulsory helmet wearing ranks very low among a long list of reasons for not riding a bicycle.

There is mixed evidence regarding the effect of mandatory helmet use for children on cycling participation in international studies. Research from locations where helmet wearing is not compulsory has identified many other factors as barriers to cycling including weather, distance, perceived levels of safety and other psychological factors.

Analyses of crash and hospital data

Crash data

Post-legislation and penalty crash data (1993-2008) were analysed because reliable earlier data are not available. The crash data does not include off-road crashes or most on-road crashes not involving a motor vehicle and possibly underestimates crashes where riders were not wearing helmets.

Most fatal bicycle crashes occur on roads where the speed limit is 60 km/h, followed by 100 km/h but some bicycle fatalities and serious injuries have occurred when signed speeds are less than 40 km/h.

The proportion of reported bicycle crashes that have resulted in fatalities and hospitalisations has increased over time which may reflect the increase in the proportion of cyclists aged 25 years or older involved in police reported crashes. The involvement of cyclists aged 0-4 in crashes has remained steady while the proportion of cyclists aged 5-11, 12-17 and 18-24 has decreased, particularly the 12-17 age group.

The proportion of cyclists injured who are not wearing a helmet appears to be decreasing but this may reflect an increase in helmet use being reported as "unknown" across all severity levels. Over time there has been a decrease in reported helmet use rates for minor injuries, while there has been a general trend to increasing helmet use rates for medical treatment and hospitalisation injuries. The helmet-use rates for fatal injuries continue to fluctuate over time because of the small numbers.

The Queensland data show reductions of 60% in the likelihood of head injury (69% in the literature), 53% for serious head injury (74% in the literature) and 58% for head and/or facial injury (65% for upper and mid-face in the literature) associated with wearing a helmet. Injuries to other body regions did not differ noticeably between helmet wearing riders and non-helmeted riders, except for shoulder and upper limb injuries.

Bicycle pillions are less likely to wear helmets than bicycle riders and are much more likely to suffer a head injury.

Recorded helmet use rates are fairly consistent across time (approximately 80%) among cyclists aged 25 years or older. Helmet use trends are the lower for younger riders, although the helmet wearing rates appear similar for primary and secondary school aged children (5-11 group and 12-17 group).

The majority of crashes occur on roadways where the posted speed limit is 60 km/h, regardless of the cyclists' age. Younger riders (aged 11 years or younger) are less likely to be involved in crashes on roadways with higher speed limits (≥70 km/h), or with very low speed limits (<40 km/h).

Fatality data

Bicycle fatality data are only available for on-road fatalities but the research evidence suggests that almost all bicycle fatalities occur on roads. Most cyclists killed are males in collisions with motor vehicles with 15-29 year olds being most commonly involved. The number of cyclists killed per year has approximately halved since the introduction of helmet legislation. The reduction in cyclist fatalities in the years following the introduction of the helmet wearing legislation was proportionally greater than for all road users, supporting the view that this related to the introduction of helmet legislation, rather than general road safety improvements. Information about helmet wearing by killed cyclists is only available for 1996 to 2000 and shows that about a third of killed cyclists were not wearing a helmet. Wearing rates were lowest by cyclists aged under 20, with a steady increase with age.

Hospital data

Analysis of hospital admissions data showed that approximately 17% of all land transport hospitalisations in Queensland are cyclists, about half of these injured in on-road and about half injured in off-road crashes. Across Australia, about half of the cyclists hospitalised are children, who are more likely to have been injured in off-road crashes than adults. Even among on-road crashes, about half of the hospitalisations result from non-collision events (e.g. falling off the bike). Head injuries were the second most common principal diagnosis for cyclists admitted to hospital from on-road crashes, after shoulder/upper limb injuries, but resulted in similar numbers of total patient days.

Similarly, emergency department data from the Queensland Injury Surveillance Unit reports injuries to the head, neck or face as second most common after injuries to the upper limb. Only 6-8% of emergency department presentations by cyclists result from a collision with a motor vehicle but these collisions are more likely to result in intracranial injury. Data from the Mater Children's Hospital has shown that the percentage of cyclists admitted with head injury has halved since bicycle helmet legislation was introduced.

Critical examination of methodology of Voukelatos and Rissel article

There are a number of assumptions made in the methodology adopted by Voukelatos and Rissel (2010) that may not be supported by findings from other research.

Voukelatos and Rissel (2010) compared the ratio of number of head to arm injuries in admitted cyclists. This may have underestimated the effectiveness of bicycle helmets by including a range of injuries that are unlikely to be prevented by bicycle helmets. The ratio of head to arm injuries differed as a function of age group, suggesting that any change in the age distribution of cyclists hospitalised could affect the overall ratio of head to arm injuries, rather than this ratio being a reliable indicator of helmet wearing effectiveness.

The paper also relied on admitted patient data. The first disadvantage of using admitted patient data is that by its very nature, it does not contain any information about the cyclists who were not sufficiently injured to be admitted to hospital (or those that died before reaching hospital). It may be these very cyclists who are benefiting from wearing helmets. This is part of a general methodological concern with using data where injury is the inclusion criteria (e.g. only including people who have been admitted to hospital) to evaluate an injury reduction measure. The second disadvantage of the approach taken by Voukelatos and Rissel (2010) is that it counts numbers of hospitalised cyclists for head and arm injuries but does not formally take injury severity into consideration. Victorian research (Carr, Skalova and Cameron, 1995) demonstrated that the severity of head injuries for crash-involved bicyclists declined after the introduction of helmet wearing legislation.

The approach taken by Voukelatos and Rissel (2010) assumes that the likelihood an injured person will be admitted to hospital, given a particular type and severity of injury, will be constant over time. However, triage practices and hospital policies change over time and there is evidence that this has occurred in relation to head injuries. Thus, there may have been increases in the likelihood that head injured cyclists would be admitted during the period 1988-89 to 2007-08 that may have masked reductions in head injury severity resulting from bicycle helmet wearing. This would have made it more difficult for Voukelatos and Rissel (2010) to detect a reduction in the head to arm ratio and therefore to find a benefit of bicycle helmet legislation.

The likelihood that an injured person will be admitted to hospital, given a particular type and severity of injury, may also vary as a function of age (and this may also change over time). Any changes in these practices over time, as well as in the age distribution of cyclists sustaining impacts to the head, could lead to changes in the head to arm injuries ratio calculated by Voukelatos and Rissel.

The relevance of New South Wales helmet use data to Queensland can also be queried. The data cited in the paper show surprisingly low wearing rates in 1991/92 (about 5% for riders aged under 16 and 15% for those aged over 16) which increased to between 75 and 85% in 1993/94 and 1995/96. Observational data from other States have shown much higher rates of helmet wearing before and immediately following the introduction of the law. In Queensland, wearing rates for primary and secondary school students were 59% and 13% with adult rates of 21-22% when measured 3 months before the legislation came into effect (King & Fraine, 1994). These interstate data call the accuracy and generalisability of the NSW helmet wearing data into question.

Similarly, it is unclear whether Queensland hospital data showed the same trends as in New South Wales. We do not currently have access to Queensland hospital data prior to 2003 so we are unable to answer this question directly. The very large variability in the numbers of cases of head and arm injuries each year (even when summed over all ages) gives one cause for concern in interpreting the ratios that are calculated.

Voukelatos and Rissel (2010) state that "it is most likely that a series of changes in road safety and conditions before 1991 contributed to a generally safer road environment, which benefited people cycling as well as other road users" (p.54). In NSW, these changes included the introduction of random breath testing in 1982, intensive road safety advertising in 1989 and speed cameras programs in 1990. A Victorian study has identified that cyclist injuries were reduced by general road safety measures, but more so by helmet legislation (Carr, Skalova and Cameron, 1995). The modeling process, which accounted for other road safety-related factors, suggested that the reduction in bicycle admissions was largely due to the helmet legislation.

It is important to note that the bicyclist hospital separations analysed by Voukelatos and Rissel (2010) resulted from both on- and off-road crashes. Clearly, road safety programs are unlikely to have affected the off-road crashes. While the authors do not present data on the breakdown of crash locations, current hospital admission data suggests that about half of the cyclists admitted to hospital were riding off-road. Thus, the claim by Voukelatos and Rissel that the reductions before 1991 resulted from changes in general road safety is weakened by their inclusion of cyclist injuries resulting from off-road crashes.

While the impact of these methodological implications cannot always be easily assessed, their overall result is to call into question the conclusion that "it is likely that factors other than the mandatory helmet legislation reduced head injuries among cyclists" (p.50).

Examination of possible segmented approaches to helmet legislation

The segmented approaches examined were:

- Mandatory helmet wearing for children only;
- Mandatory helmet wearing when riding on roads with a speed limit of over 40 km/h; and,
- Mandatory helmet wearing when riding on roads but not on bicycle paths or footpaths or off-road.

There are no exact methods to generate accurate numerical predictions of what the effects of changing to a segmented approach would be. A combination of available data on police-reported on-road bicycle crashes and hospitalisation data for on- and off-road crashes supplemented by a range of assumptions was used to provide indications of the possible effects on head injuries to cyclists.

All of the proposed approaches to segmenting bicycle helmet legislation were predicted to result in substantial increases in the percentage of riders in crashes who sustain head injuries. The values that follow are based on a halving of wearing rates if it was no longer mandatory. If helmet wearing was required only for riders aged under 18, then this would result in an increase of about 14% in the number of cyclists sustaining head injuries in on-road crashes (according to Police-reported data) or an increase of about 20% in both on- and off-road cyclist head injuries, according to hospital data. Any change in helmet wearing legislation that no longer required helmet wearing when not on public roads is predicted to result in an increase in head injuries of about 26% in off-road crashes, and an indirect increase in on-road cyclist head injuries of about 10%.

General conclusions

Current bicycle helmet wearing rates are halving the number of head injuries experienced by Queensland cyclists. This is consistent with published evidence that mandatory bicycle helmet wearing legislation has prevented injuries and deaths from head injuries. It is reasonably clear that it discouraged people from cycling twenty years ago when it was first introduced. Having been in place for that length of time in Queensland and throughout most of Australia, there is little evidence that it continues to discourage cycling. There is little evidence that there is a large body of people who would take up cycling if the legislation was changed.

Cycling does have significant health benefits and therefore should be encouraged in ways that reduce the risk of the most serious of injuries. Head injuries not only have the potential for death but they are among the most disabling of non-fatal injuries (in some ways more than spinal injuries). Infrastructure and speed management approaches to improving the safety of cycling should be undertaken as part of a Safe System approach, but protection of the individual by simple and cost-effective methods such as bicycle helmets should also be part of an overall package of measures.

1. INTRODUCTION

Recent research on bicycle helmets and concerns about how public bicycle hire schemes will function in the context of compulsory helmet wearing laws have drawn media attention. A recent research paper (Voukelatos & Rissel, 2010) questions the merit, safety and value of wearing bicycle helmets. The Queensland Department of Transport and Main Roads (TMR) wishes to develop a policy paper that will examine the available evidence concerning the benefits and disadvantages of compulsory bicycle helmet wearing legislation. They have commissioned the Centre for Accident Research and Road Safety – Queensland (CARRS-Q) to review the available research and data to inform the development of the policy paper.

1.1 Project objectives

The primary objective of this assignment is to examine the available evidence concerning the benefits and disadvantages of compulsory bicycle helmet wearing legislation, to inform a policy paper.

As per the Consultant's Brief, this was achieved through:

- Undertaking a comprehensive literature review that investigates the safety benefits of bicycle helmet wearing as well as the possible negative effects on cycling participation;
- Analysing Queensland and Australian crash data and hospitalisation data to determine the extent of injuries to cyclists with and without helmets. This will be broken down into type of injury, age of cyclist, where it occurred (on or off-road);
- Analysing attitudinal surveys (WAVE) and other available attitudinal data to examine any reported disincentives to cycling from compulsory helmet wearing; and,
- Critically examining the methodology that Voukelatos and Rissel (2010) use in their paper on helmet wearing and head injuries.

Two additional objectives related to:

- Examining evidence to support a segmented approach to mandatory helmet legislation; and,
- Analysis of the public health argument for bicycle use.

1.2 Project methodology and report structure

The project methodologies included a review of the national and international literature relating to the health effects of cycling (Ch 2) and bicycle helmets (Ch 3), analysis of Police-reported crash data from Queensland supplemented by a review of published crash and injury data (Ch 4) and an integration of these results (Ch 5). This was followed by a critical examination of recent articles arguing against compulsory helmet use (Ch 6) and an examination of some possible segmented approaches to bicycle helmet wearing legislation (Ch 7).

The literature reviewed in this report includes:

- Research articles published in peer-reviewed scientific journals;
- Presentations and papers from a range of national and international transportation and public health conferences;
- Government reports from Australia and internationally; and,
- Commissioned reports available from local and international research centres.

There is a very extensive literature on bicycle helmets, legislation and cycling participation. Many of the authors are advocates of either cycling or road safety, some of whom have fundamental differences in how they value injury and other health outcomes. There are numerous alternative explanations provided of the same data, as well as questioning the validity of data collection methods and results. While the material presented is generally accurate, other conflicting information may be omitted or limitations not pointed out, thus biasing the interpretation. In our approach to this literature we have attempted to present what we consider to be the most reliable research, but it must be acknowledged that this paper has been written by road safety researchers (who are also cyclists) and therefore it may be criticised by those whose focus is on cycling participation or public health in general.

2. HEALTH OUTCOMES OF CYCLING

This section reviews the literature regarding the positive and negative health outcomes associated with cycling. This task involved a review of the published research regarding the health benefits of cycling and other forms of physical activity. The amount of cycling required to obtain a health benefit was compared with published data regarding cycling frequency and duration. The relative costs of injuries versus the health benefits of cycling were also examined. In particular, the relevance of published research to Queensland was assessed.

In this area, as in many other areas of the literature, the work has been carried out and interpreted by advocates, which may limit the range of data examined and the interpretations considered.

The effects of bicycle riding on health can be positive or negative and can be divided into those which are direct to the individual and indirect effects on society as a whole. Elvik (2000) notes that the net effect on health of walking and cycling to the individual is the outcome of three impacts: (i) exposure to the risk of road crashes, (ii) exposure to air pollution from walking or cycling close to motor vehicles, and (iii) walking and cycling as a form of physical exercise. Indirect benefits may accrue to society if increased cycling results in less car use and therefore reductions in air pollution. The following sections first summarise the wider research on the benefits of cycling in reducing levels of diseases linked with inactivity, then the research relating to effects of air pollution on cyclist health and finally, injuries to cyclists.

2.1 Effects of cycling on diseases linked with inactivity

A large number of studies have sought to examine the relationship between physical inactivity and increased mortality and morbidity. Some studies have focussed on cycling, while others have included a range of different types of physical activities. The diseases where a link has been demonstrated with inactivity include all-cause mortality, cardiovascular disease, cancer (all, colon, breast and lung), Type 2 diabetes, and depression (Genter et al., 2008).

There are many factors that affect both health and the likelihood of cycling, making unambiguous links between cycling and better health outcomes difficult. For example, people who cycle more may be less likely to smoke and be more likely to engage in other forms of physical activity than non-cyclists, factors which are also associated with better health outcomes. Demonstrating an association between cycling (or even the amount of cycling) and better health outcomes does not, by itself, guarantee that cycling caused the better health outcome. It may be that people who have better health are more likely to cycle. While it would be good to have evidence from a randomised control trial to show that those assigned to the cycling condition improved their health more than others, the research evidence is that interventions to improve cycling have only limited effectiveness. It appears we cannot force randomly assigned individuals to become cyclists for research purposes.

In a Copenhagen study (Andersen et al., 2000), many of the potential factors that could confound the relationship between cycling and mortality were measured and controlled for, including age, gender, educational level, smoking status, a range of cardiovascular measures at the beginning of the study and body mass index. In addition, a number of different measures of physical activity were assessed, including leisure time physical activity, sports participation, physical activity at work (including housework), and bicycling to work. The relative risk for all-cause mortality was found to be 0.72 for regular commuter cyclists, which equated to a 40% lower chance of dying in a given year compared to non-cyclists. Andersen et al. (2000) concluded that "in both sexes and in all age groups there was a lower mortality in the physically active compared with the inactive. Those who used a bicycle as transportation to work experienced a lower mortality rate even after adjustment for leisure time physical activity, and sports participation discriminated mortality rates even the among the more physically active subjects" (p. 1627).

A number of the studies of the effects of physical activity on mortality have demonstrated different findings for males and females (see Bucksh, 2005). Andersen et al. (2010) reports that some studies failed to find an effect for women because they did not measure the amount of physical activity in housework and looking after small children. In a German sample, Bucksh (2005) found that moderate intensity of physical activity in leisure time reduced mortality in women, but not in men. This study had a smaller sample than Andersen et al.'s (about 3,000 of each sex, compared with 13,000 men and 17,000 women), which may have contributed to the relative risk not being significant for women. However, Bucksh controlled for similar factors as Andersen et al. (social class, body mass index, cardiovascular disease risk factors). Bucksh examined four predictors: overall volume of physical activity, volume of activities of moderate intensity and duration of moderately intense physical activity (above or below the CDC recommendations) (Centres for Disease Control and Prevention, 2010). The results showed that overall physical activity was related to mortality, with greater reductions for women than men, and greater reductions at the highest level of overall physical activity. All-cause mortality dropped with the volume of moderately intense physical activity for women but was not generally statistically significant for men.

The Australian Institute of Health and Welfare (AIHW, 2009) has concluded that insufficient weekly levels of physical activity are associated with a number of conditions, including cardio-vascular disease, Type 2 diabetes and chronic kidney disease. BMA (1992) and Genter et al. (2008) review a large number of studies of the effects of physical activity on morbidity. Compared to inactive individuals, those who are physically active have been found to have a reduction in the risk of cardiovascular disease of between 20 and 35% (Macera et al., in Genter et al., 2008) and Type 2 diabetes of 35-50% (Lynch et al. 1996; Manson et al., 1992). Physical activity has been shown to reduce obesity which is a risk factor for a many diseases, including cardiovascular diseases, Type 2 diabetes and several cancers. Frank, Andresen and Schmidt (2004, cited in Genter et al., 2008) found that each additional kilometre walked per day was associated with a 5% reduction in the odds of being obese. Physical activity has been found to be associated with reductions in colon cancer (30-40%), breast cancer (20-30%) and lung cancer (20%, although part of this may be less smoking by cyclists). There is evidence that physical activity is beneficial in the prevention and treatment of depression and other mental health problems (Genter et al., 2008).

Hendriksen, Simons, Garre and Hildebrandt (2010) concluded from a Dutch study of absenteeism that commuter cycling was associated with one less day per year of sick leave on average (largely resulting from more cyclists having taken no sick leave). This is larger than the 1% reduction in short-term absence from work assumed in an earlier study (Saelensminde, 2004). The more often people cycled to work and the longer the distance the greater was the reduction in absenteeism. However, high cycling speed was associated with increased absenteeism. Hendriksen et al (2010) is a cross-sectional study and despite the observed dose-response relationship, the results could reflect more cycling by healthier people, rather than cycling resulting in better health. While the title of their paper refers to an association between commuter cycling and sickness absence, their conclusions about encouraging employers to implement commuter cycling programs assume causality.

2.1.1 Issues in estimating the health benefits of cycling from increasing physical activity

Several issues have arisen in undertaking studies of the health benefits from increasing physical activity by cycling participation. Some of the main issues are:

- How much cycling is needed to obtain a health benefit?
- How many people currently gain a health benefit from cycling?
- How should the economic benefits of active travel be measured?

2.1.1.1 How much cycling is needed to obtain a health benefit?

The exercise requirements to gain health benefits have been widely examined. The minimum recommendation for adults is 150 minutes of moderate-intensity aerobic activity (or 75 minutes of vigorous-intensity activity and strength activities, or an equivalent mix of moderate- and vigorous- intensity aerobic activity) and strength activities on 2 or more days, every week (Centres for Disease Control and Prevention, 2010). Physical activity bouts need to be a minimum of 10 minutes in duration to count towards a weekly tally. The recommendations vary slightly for children and older adults. More physical activity provides additional health benefits. Approximately 70% of Australians undertake insufficient weekly levels of physical activity.

Commuting to work by bicycle (mean one-way trip 9.7km), at an average speed of 17.6 km/h, has been shown to improve fitness (VO2max, Time to Fatigue) and HDL cholesterol levels (Oja et al, 1998).

The literature suggests that there are health benefits to cycling that occur when the amount of cycling passes a lower threshold value and which cease once the amount of cycling passes an upper threshold. Some of the studies reviewed by Genter et al. (2008) assign a threshold value below which the increase in physical activity is not considered to provide a measurable health benefit. For example, Boaranet et al. (2008, cited in Genter et al., 2008) calculated an increase in lives saved only for those who walk enough to move from the first to second tertile of physical activity. Some of the studies also assign an upper value to physical activity, beyond which no benefit is calculated.

2.1.1.2 How many people currently gain a health benefit from cycling?

The existence of lower and upper thresholds of amount of cycling to gain a health benefit makes it difficult to estimate how many people currently gain a health benefit from cycling.

Cavill et al. (2008) identified the relationship between observed cycling or walking and total physical activity as one of the most significant challenges for economic analyses of the health benefits of walking and cycling. They claim that most studies do not have information on energy expenditure and so rely on assumptions about how much impact the observed walking and cycling has had on total physical activity. The issue of activity substitution is an important one, in which increases in cycling may result in a reduction in other forms of physical activity (e.g. riding to work replacing gym sessions), leading to an over-estimate of cycling benefits.

Genter et al. (2008) Table 9 provides a useful approach by weighting the health benefits of cycling by activity status (sedentary=1, inactive=0.85, active=0.15) and weighting this again by the prevalence of each activity status in the New Zealand population (sedentary=0.15, inactive=0.345, active=0.505). Approximately 70% of Australians undertake insufficient weekly levels of physical activity (AIHW, 2009).

The Sustainable Transport Survey 2010 (MCR, 2010) found that the mean frequency of riding for Queensland adults who own a bicycle in working order is 52 times per year. Only 4% rode daily and 17% rode more than once a week. The mean duration of a normal ride was 41 minutes, with 41% reporting a duration of less than 30 minutes. Thus, many people who are described as current riders may not ride enough to gain a health benefit solely from cycling.

2.1.1.3 Economic estimates of the value of active travel

Methods of estimating the economic value of active travel differ in terms of what types of impacts they include and the values given to these impacts, as well as in the number of people they assume to be impacted. These are discussed in more detail in a later section. This section focuses on the values given to the health benefits of active travel.

The Land Transport New Zealand Economic Evaluation Manual (EEM2) (Genter et al., 2008) values the health benefits for new pedestrians at 40 c/km and all cyclists at 16 c/km. It does not recognise the health benefits for existing pedestrians or for other active mode users (skates and scooters).

A recent New Zealand report (BECA, 2007 cited in Genter et al., 2008) valued the health benefits of moving a person from inactive to active health status in terms of willingness to pay for disability adjusted life years, health sector costs and lost output resource costs. Benefits were estimated at 80 c/km for walking and 40 c/km for cycling, with a cap on the annual health benefits of $1,000 per user. Cycling is assumed to have half the benefit per km of walking (from four times the speed but twice the exercise intensity) (Genter et al., 2008).

Other studies have used much lower values for health benefits. The cost-benefit analysis of completing nine major missing links of the Sydney Metropolitan Cycle Network (PricewaterhouseCoopers, 2009) assumed health benefits of 1.42 c/km.

Genter et al. (2008) recommended that their medium estimates of $3,756 per year or $2.14 per km of cycling be applied in full to new cyclists and in half to existing cyclists. These values are in 2007 $NZ.

2.2 Effects of air pollution on the health of cyclists

There has been concern that the health of cyclists may be damaged by inhaling more pollutants when riding near motor vehicles because of increased breathing rates. This is supported by some evidence that inner-city areas where walking and cycling trips may be feasible alternatives may also have higher levels of air pollution because of traffic congestion (Marshall et al., 2009 cited in de Hartog et al., 2010).

Some studies have compared the concentrations of particulates inside cars and on bicycles. In Belgium, Bleux et al. (2009) reported higher concentrations inside cars but the higher breathing rate of cyclists compared to drivers meant that they were still more exposed to particulates. De Hartog et al (2010) reached the same conclusion by reviewing eight published European studies.

Greaves and Hamers (2006) reported one of the few Australian studies that examined exposure to fine particulates while cycling. Fine particulates (particularly those with a diameter of less than 2.5 microns) are able to penetrate deep into the lungs where exchange with blood may occur. They used a combination of a personal GPS device attached to the handlebars of the bicycle and an air sampling tube strapped to the helmet near the mouth and nose (connected to a monitor attached to the back of the cyclist). Data were collected in Sydney during May and June 2005. The highest concentrations of fine particulates were observed in the morning peak, and on highways, almost double that on other roads. The concentrations measured on off-road tracks and paths were just under a third of those on highways. Hot spots with concentrations about 100 times greater were identified which had much higher concentrations than other locations. These included the approach and exits of intersections, travelling uphill in medium heavy traffic and where the road narrowed.

De Hartog et al (2010) note that most of the studies of air pollution on health have examined long-term exposure, rather than the short exposures likely to occur during cycling. In their review, they present the results of four recent studies. McCreanor et al. (2007, cited in De Hartog et al., 2010) and Strak et al. (2010, cited in De Hartog et al., 2010) both reported decreases in lung function after exposure to traffic fumes. Riediker et al. (2004, cited in De Hartog et al., 2010) found that policemen after an 8-hour shift that exposed them to ultrafine particles at the World Health Organization daily limit demonstrated a variety of heart rate and blood changes.

De Hartog et al (2010) derived mortality risk estimates for exposure to traffic-related fine particulates and black smoke at both an individual and a societal level associated with cycling versus driving a car. At an individual level, the relative risk of mortality associated with cycling instead of driving a car was estimated at between 1.026 and 1.053. At the societal level, more cycling can reduce air pollution levels for the general population. Using a Dutch air pollution model, they estimated that a 12.5% reduction in traffic volumes could result in a mortality rate 1.012 times lower for the 800,000 to 160,000 people living in major streets in the Netherlands.

The general conclusion of most of this research has been that the benefits of physical activity outweigh the negative effects of exposure to air pollution (Pearce et al., 1998, cited in Elvik, 2000).

2.3 Cyclist injury and fatality risks and patterns

Bicycles can be ridden on- or off-road and the associated risks and injury patterns are likely to differ. For both on- and off-road riding, there are challenges in the completeness of both crash or injury and distance ridden data that make description of injury and measurement of risk difficult. Some of the issues related to the bias and under-reporting to police of on-road crashes are discussed in Chapter 3.

Fatality and injury rates for on-road riding in Australia have not been available since the 1980s because of lack of comprehensive data on distances ridden. Data from the New Zealand Household Travel Survey was combined with Police-reported crash data (which included only those cyclist crashes that involved motor vehicles) to estimate the risks of different forms of road transport (Ministry of Transport, 2008). As a function of distance travelled, motorcycling was the most risky (473 deaths or injuries per 100 million km travelled), followed by cycling (300), driving a light 4 wheeled vehicle (27), being a passenger in a light 4-wheeled vehicle (18) and being a passenger in a bus (2.5). Given the lower speed of cycling compared to other modes, the cycling risks were relatively lower when expressed as a function of hours of travel, rather than distance travelled. In terms of hours of travel, motorcycling remained the riskiest mode (132 deaths or injuries per million hours travelled), followed by cycling (36). Drivers of light 4 wheeled vehicles had a higher risk (10 deaths or injuries per million hours travelled) than passengers in light 4 wheeled vehicles (7), and the two safest travel methods were walking (5) and being a bus passenger (0.7). The major difference is that cycling has a much larger risk by distance (11 times the risk of driving), than by time (only 3.5 times larger than the risk by driving).

Similarly, data from Great Britain for police-reported on-road injuries show casualty rates for cyclists that are less than for motorcycle riders but greater than for car drivers. In 2009, there were 34 cyclists killed per billion miles ridden compared with 140 for motorcycle riders and 2.8 for car drivers (Department for Transport, 2010). The fatality rate for cyclists in 2009 was lower than in any of the previous 10 years (as it was for motorcycle riders and car drivers), when it ranged from 39 in 2008 to 67 in 1999. The death and serious injury rate was 875 per billion miles for cyclists, 1,709 for motorcyclists and 30 for car drivers. For all injury severities, the rate was 5,505 injuries per billion miles for cyclists, 6,085 for motorcycle riders and 387 for car drivers.

For on-road injuries, the greater completeness of hospital admission data compared with police-reported data generally leads to higher estimates of cyclist injury rates. Data presented by Gill and Goldacre (2009) allows the ratios of hospital admissions for road traffic injuries and of trips for car drivers and occupants versus cyclists in the UK to be compared. This comparison shows that cyclists are 20 times more likely to be admitted to hospital per trip than car occupants.

Injury rates have also been calculated from self-reported injury involvement and riding patterns. Using this method, a Canadian study concluded that, per kilometre travelled, cyclists are between 26 and 68 times more likely to suffer an injury compared with motor vehicle travel (Aultman-Hall & Klatenecker, 1999).

However, fatality risks for cycling vary considerably across countries. Averaged over 2002-2005, the cyclist fatality rate per million kms cycled was 5.8 in the United States, 3.6 in the United Kingdom, 1.7 in Germany, 1.5 in Denmark and 1.1 in the Netherlands (Pucher and Buehler, 2008). Pucher and Buehler (2008) cite OECD data that suggests that the pattern is similar for non-fatal injury rates. They argue that the countries with the lowest fatality and injury rates are those where there is substantial investment in cycling infrastructure and high cycling rates (e.g. the Netherlands and Scandinavia).

Research suggests that fatality and injury risks differ according to characteristics of the rider and the type of riding. Research from Sweden found that the mortality rate for bicycle crashes was 9.4% for males and 5.4% for females (Bostrom & Nilsson, 2001).

Bicycle injuries are one of the primary causes of presentation to emergency departments for children (Thomas et al, 1994). However, it is difficult to measure the number of cycling injuries as most minor injuries often require no treatment or self-treatment (Kloss et al, 2006). Research into mountain biking injuries found that 21.8% of injuries were left untreated, while 48% of injuries were self-treated (Chow et al, 1993).

Bicycle-related injuries occurring in Victoria have been examined (Sikic et al, 2009). The majority of patients treated for bicycle-related incidents were male, most likely reflecting rider patterns. Emergency department presentations were most likely to occur as a result of injuries to the extremities. The majority of major trauma cases involved multiple injuries, with the most common injuries being the trunk (51%) and head/neck/face (44%). The proportion of trunk and head/face/neck injuries in major trauma cases was significantly higher compared with emergency presentations and admissions. The majority of fatalities involved head trauma. When the use of helmets was examined for fatalities, 48% were wearing helmets, 15% were not wearing helmets and in 36% the use of helmets was unknown.

A British study of cyclists presenting to a hospital emergency department found that upper limb injuries are the most frequently sustained type of injury in bicycling crashes (64%), followed by lower limb (24%), head (23%) and facial (22%) injuries, with very few trunk/neck injuries (Davidson, 2005). This agrees with hospitalisation data for Britain for 2009 (The Stationery Office, 2010) which showed that cyclists discharged as emergency road casualties most commonly had injuries to the arms/shoulders (45%), followed by head/face (37%) and then legs/hips (about 25%). Cyclists were less likely to have injuries to their neck or back than other road users. Cyclists aged 65 and over had relatively fewer injuries to the arms/shoulders and more injuries to the legs/hips than younger riders.

2.3.1 Effects of riding location and infrastructure

A large body of research has examined the relative safety of cycling in different locations, ranging from mountain biking trails through to rural highways. Not only does the type of location vary dramatically, so does the motivation for riding and the characteristics of riders. As has been pointed out in the literature, comparisons of the safety performance of different types of infrastructure may be confounded by differences in gender or age profiles of cyclists who use these types of infrastructure or different levels of skill or risk-taking behaviour (Reynolds et al., 2009). In addition, there are shortcomings of crash and injury data for cyclists and even larger problems with detailed data regarding riding patterns. Hence the research requires careful examination before any tentative conclusions can be drawn.

Off-road cycling is both popular and a significant contributor to bicycle-related trauma. In Australia, off-road riding contributes almost half of the hospitalisations as a result of bicycle crashes (Henley & Harrison, 2009). Interviews with hospitalised riders in Western Australia found that the majority (58%) of injuries occurred off-road, on sidewalks, driveways, yards, cycle paths, car parks and bike trails (Meuleners, Lee & Haworth, 2007). Yet little research has examined the factors affecting choice of where to ride off-road. The recent review of infrastructure effects on safety (Reynolds et al., 2009) specifically excluded "studies of injuries or crashes that occurred when the bicycle was being used for bicycle racing, 'off-road mountain-biking', trick/trials riding, or play".

Mountain biking is perhaps at one extreme of the infrastructure spectrum, being characterised by very uneven surfaces, steep gradients and narrow tracks. The facial injuries sustained by road riders and mountain bikers in Austria have been compared (Kloss et al, 2006). The mechanisms of injuries differed between riding types, as did the distribution of both age and gender. The mean age of mountain bikers involved in accidents was higher (34 years compared with 25 for bicyclists). Males represented a higher proportion of injured mountain bikers (71% compared with 60% of road riders). Several mechanisms of injury were identified: falls, collisions with objects, struck by equipment, collisions with other person, and traffic collisions. Falls, collisions with other person, and struck by equipment were similar between bicycling and mountain biking accidents. Collisions with objects was a more common mechanism of injury for mountain bikers

(6% vs 2%), while traffic collisions were more common for bicyclists (10% vs 3%) (Kloss et al, 2006).

In terms of more traditional riding, road infrastructure characteristics affect both the popularity of bicycling (Dill & Carr, 2003; Pucher & Buehler, 2008) and its safety (Reynolds, Harris, Teschke, Cripton & Winters, 2009). A recent review of the literature from developed countries (Reynolds et al., 2009) concluded that clearly-marked, bicycle-specific facilities (including cycle tracks at roundabouts, bike routes, bike lanes and bike paths) were safer than on-road cycling with traffic or off-road with pedestrians and other users.

The relative safety of different forms of infrastructure needs to be considered both in terms of the risk of crashes occurring and the severity of the outcomes. The most severe outcomes are likely to occur in crashes with motor vehicles on roads with high speed limits. This is supported by US data which shows that police-reported bicycle crashes on rural roads are three times more likely to result in a fatality (Carter & Council, 2006).

The assessment of the risk of crashes occurring on different forms of infrastructure is more difficult. Official databases generally lack complete reporting of crashes and detailed usage information. Thus many studies are forced to rely on surveys that collect self-reported data regarding crashes and riding patterns. There is potential bias in the respondents to these surveys, and limits to sample sizes often mean that the analyses include mostly crashes of very low severity. For example, a survey in Toronto with responses from 1196 cyclists included 300 collisions and 303 falls but only 15 injuries that required medical attention (Aultman-Hall & Kaltenecker, 1999). Thus the crash rates may be most applicable to crashes of very low levels of severity, which are arguably of low priority for prevention.

Importantly, the relative crash rate associated with different types of infrastructure may differ according to the levels of crash severity that are measured. Several North American surveys found that crash rates were higher on footpaths than on roads (Moritz, 1997; Aultman-Hall & Hall, 1998; Aultman-Hall & Kaltenecker, 1999). Yet the sample of crashes was largely of such a low severity that medical attention was not required. Another concern in interpreting this data is the lack of ability to compare the footpath crash rates with cycling on the road at the same location. It may be that the roads were considered particularly unsafe at these locations, resulting in footpath cycling, and that the cyclists may have been objectively safer (at least in terms of avoiding serious injury) on the footpath.

Another caveat in interpreting the studies of cycling infrastructure safety is that the same terms may be used to denote types of infrastructure that differ between countries. For example, in some studies the term "off-road path" may refer to segregated, well-constructed bike paths, but in other studies it may refer to multi-use paved or unpaved paths or trails (Aultman-Hall & Kaltenecker, 1999).

2.3.2 Issues in measuring the costs of injury resulting from cycling

There are a number of challenges in estimating values of injury from cycling for comparison with health benefits. Some of these relate to different ways of costing injury and other health outcomes and some relate to measuring the true frequency and severity of cycling injury.

2.3.2.1 Ways of costing injury and other health outcomes

Most injury costing estimates use the human capital approach but health benefits may use willingness to pay instead. When willingness to pay is applied to road crash injury, estimates of injury costs are generally several times greater.

2.3.2.2 Measuring the true frequency and severity of cycling injury

The data reported in Section 4.2 of this report demonstrates the substantial level of under-reporting of on-road cycling crashes with estimates that Police-reported data may capture only 3.5% (Hendrie & Ryan, 1994) to 13% (Veisten et al., 2007) of reportable bicycle crashes. For off-road cycling crashes, the most satisfactory data only relates to hospital admissions and many crashes result in a lower level of injury. While lower levels of injury may have lower associated costs, their greater frequency may mean that the total costs of low severity injury may be considerable.

Recent surveys have suggested that there are a considerable number of injuries associated with cycling that are not related to crashes. Schramm et al. (2010), reported that among 2,500 Queensland cyclists, 27% reported sustaining a non-crash injury in the previous two years, compared with 52% reporting a crash injury in the same period. Non-crash incidents were responsible for 24% of the most serious injuries in the previous two years.

2.3.2.3 Understanding safety in numbers

Cycling advocates and researchers often refer to safety in numbers as a principle describing an improvement in safety with increasing levels of cycling participation. Safety in numbers has implications for the health outcomes of cycling because it suggests that injury costs per individual will decrease as cycling participation increases, while health benefits will remain constant.

The expression "safety in numbers" appears to have been first used by Jacobsen (2003). He concluded from an analysis of several previous studies that "where, or when, more people walk or bicycle, the less likely any of them are to be injured by motorists. There is safety in numbers" (p.209). He examined two types of earlier studies. Three studies (from California, Denmark and 14 European countries) compared the number of collisions between pedestrians or cyclists and motor vehicles in different cities or countries with measures of the amount of walking and cycling. Two additional studies compared collisions with the amount of walking and cycling in the same locations (United Kingdom, the Netherlands) over a period of years. These studies all show that the increase in the number of collisions between motor vehicles and cyclists and cyclists increases less than linearly with the amount of walking and cycling.

Jacobsen concludes that "the number of motorists colliding with people walking or bicycling will increase at roughly 0.4 power of the number of people walking or bicycling. For example, a community doubling its walking can expect a 32% increase in injuries. An individual's risk while walking in a community with twice as much walking will reduce to 66%. Accordingly, policies that increase the numbers of people walking and bicycling appear to be an effective route to improving the safety of people walking and bicycling" (p.208).

Given the rapid changes in the time series data, Jacobsen (2003) argues that the most plausible explanation of the finding is adaptations in motorist behaviour as a function of numbers of pedestrians and bicyclists, rather than changes in roadway design, laws and social mores. He cites a US study that shows motorist speeds appear to drop when they see more pedestrians and also argues that the likelihood that the driver sometimes cycles or walks may increase, and therefore the driver may give more consideration to pedestrians and cyclists.

In Jacobsen's (2003) analyses, increases in walking and cycling were found to lead to lower risk to the individual, but an increase in total motor vehicle crashes involving pedestrians and cyclists was still predicted. Some more recent research has focused on whether the reduction to risk to the individual could be large enough to result in an overall reduction in crashes.

Elvik (2009) has reported an exploration of whether an increase in walking and cycling can lead to a reduction in crashes and what rates of walking and cycling would be needed to bring this about. He presents data that shows, with current modal splits, that injury rates per million kilometres of travel in Norway for pedestrians are about 4 times those for cars and for cyclists are about 7.5 times those for cars. He reviews a range of studies that show that the risk of injury to pedestrians and cyclists is non-linear, with the risk to an individual reducing as the number of pedestrians and cyclists increases (safety in numbers) and increasing as the number of motor vehicles increases.

To estimate the pedestrian and cyclist volumes needed to bring about a reduction in crashes, Elvik (2009) used a number of accident models and initial values of motor vehicle, pedestrian and bicyclist volumes. He then examined the outcomes of six scenarios which represented various combinations of volumes and other assumptions.

The first scenario involved a doubling in the number of pedestrians or cyclists (to 400 and 200 per day, respectively), with a corresponding reduction in the number of motor vehicles. This resulted in very small changes in the number of crashes estimated by the model. Reducing the number of motor vehicles by 25% or 50% (the second and third scenarios), with 2/3 becoming pedestrians and 1/3 becoming cyclists was predicted to lead to a reduction in the number of crashes at all traffic volumes (for the 25% reduction the effect was very small at the highest initial traffic volume of 30,000 motor vehicles per day).

Under the fourth scenario, the first three scenarios were re-examined after reducing the parameter that related motor vehicle volumes to crash numbers but increasing the parameters that related pedestrian and cyclist volumes to crash numbers. When this occurred, the number of crashes increased except when 50% of trips by motor vehicle changed to walking and cycling at low volumes of motor vehicles.

In scenario five, the opposite approach was taking (increasing the parameter for motor vehicles and decreasing the parameters for pedestrians and cyclists). The results changed very little. Elvik (2009) concluded that it is not the absolute levels of the parameters that are relevant, but whether the values are lower for pedestrians and cyclists than for motor vehicles. When this occurs, the safety in numbers effect "kicks in with full force" (p.852), but otherwise the effect is too small to prevent an increase in the total number of crashes.

In the sixth scenario, the ratio of pedestrians to cyclists was reversed (as might apply in the Netherlands and Denmark), which produced little difference in the results.

There are a number of caveats to the analysis that Elvik (2009) points out. First, the relative injury rates for cyclists (and possibly pedestrians) that he used may be too low, because of the under-reporting of cyclist crashes. He queries whether the safety in numbers effect applies to the non-reported crashes, which are assumed to be largely single vehicle crashes. However, if most of the non-reported crashes are of very low severity level, this may not be a major concern.

The second caveat relates to uncertainty regarding the exact shape of the non-linearity of risk. Previous studies have found more or less non-linearity, and he speculates that the extent of non-linearity may differ as a function of the mix of motor vehicles, pedestrians and cyclists.

Thirdly, he expresses concern about the potential increase in cyclist-cyclist crashes as cyclist volumes increase. The fourth caveat relates to whether the values used for transfer of trips from motor vehicles to walking and cycling are at all realistic. He points out that many trips are of a length that replacing by cycling or walking is theoretically possible, but that most of these trips are taken by car and such behaviour is hard to change.

The final caveat is that there may be a limit to the safety in numbers effect when the traffic is dominated by pedestrians and cyclists and there are few motor vehicles, as in some low-income countries. The crash rate per vehicle may be high because pedestrians and cyclists are unaware of how to interact with motor vehicles.

A recent Dutch analysis of the effect of exchanging car for bicycle trips found that that expected outcomes depended on the age groups whose behaviour changed (Stipdonk & Reurings, 2010). Overall, they predicted 4-8 fatalities and approximately 500 more serious injuries if 10% of car trips were replaced by cycling. However, if young car drivers became cyclists, then the number of fatalities would decrease but it would increase if older car drivers became cyclists. The number of serious injuries increased for all ages, except for 18-19 year old males.

Turner, Roozenburg and Francis (2006) developed accident prediction models for cyclist-motor vehicle crashes using data from Christchurch, New Zealand. In one scenario, they examined the effects of increasing the number of cyclists, with each cyclist replacing one motor vehicle. For each of the types of locations examined (signalised crossroads, roundabouts and strip shopping centres), the crash rate for cyclists drops dramatically with the percentage increase in cyclists, confirming the safety in numbers effect. For a 300% increase in cyclist numbers, the total number of cyclist crashes at signalised crossroads and at strip shopping centres changed very little, while the number of crashes at roundabouts increased by 50%.

Taylor et al. (2006) also present at theoretical analysis of the effects of a very large increase in cycling (15-fold) that would result in cyclists being 20% of all trips at six signalised intersections in Christchurch. Their analysis showed a small increase in cyclist crashes which was offset by a larger decrease in motor vehicle crashes. Their calculations predict that the crash rate for cyclists drops below that for motor vehicles once the percentage of cyclists exceeds 8%. However, they caution that their calculations are based on data for much lower current cycling rates and may not be valid at the extreme increases presented in their theoretical analysis.

Safety in numbers effects were found in Australian data presented by Robinson (2005). She demonstrated that the cyclist fatality rate (per 100,000 kms ridden) was lower in states and territories where the average distance travelled per person per day using data from the mid-1980s. Data from a similar period in Western Australia demonstrated that increases over time in numbers of regular cyclists were accompanied by reductions in the rate of deaths and serious injuries per 10,000 regular cyclists. In addition, reductions in cycling immediately after the introduction of helmet laws were associated with increases in the rate of head injuries relative to those sustained by pedestrians.

2.4 Comparisons of health benefits and disbenefits

Several authors have attempted to estimate the net outcomes of cycling or cycling infrastructure on health or a wider range of societal outcomes (Saelensminde, 2004; Genter et al., 2008).

Elvik (2000) identified a range of impacts of measures to improve the safety or mobility of pedestrians and cyclists that were not included in impact assessments and cost-benefit analyses at the time. These were: (a) changes in the amount of walking and cycling, (b) changes in travel time for pedestrians and cyclists, (c) changes in road user insecurity (feelings of unsafety) and (d) changes in road user health state. He cautions that there is little in the way of accepted values for these impacts.

Saelensminde (2004) undertook cost-benefit analyses of walking and cycling tracks in three Norwegian cities. The author notes that while it is common practice to conduct benefit-cost analyses for road investment projects, this is rarely done for projects primarily aimed at increasing the safety of pedestrians and cyclists, possibly because the potential effects are harder to measure (or accepted values do not exist). An important challenge in estimating benefit-cost ratios for cycling infrastructure is to have realistic distributions of current and future usage. Saelensminde (2004) reports sensitivity analyses based on high and low values of transport distributions.

Saelensminde (2004) included the following benefits in the analysis: reduced injury costs (assumed to be none), reduced health costs for less severe diseases and more severe diseases, reduced external costs (e.g. air pollution, congestion and noise), reduced parking costs, reductions in feeling of insecurity that cyclists feel on roads, travel time savings for cyclists on improved infrastructure compared to existing infrastructure, and a reduction in cost of operating public transport if users switch to walking or cycling. The costs included: direct construction and maintenance cost of the cycling infrastructure, and cost of any infrastructure needed to access the cycling facility (safer crossing and parking facilities).

The net benefit:cost ratios for investments in walking and cycling networks were 2.94, 4.09 and 14.34 in the three cities in the "best estimate" analysis. Using extreme values in the sensitivity analysis led to net benefit:cost ratios ranging from about zero to about roughly double the "best estimate" values. The largest contributor to benefits in each city was reduced costs related to severe diseases and ailments which made up half of more of the total benefit. Other major contributors to total benefit were reduced costs related to less severe diseases, reduced insecurity for cyclists and reduced parking costs for employers (particularly in the largest town). The largest contributor to costs was capital costs of construction.

Cavill, Kahlemeier, Rutter, Racioppi and Oja (2008) prepared a systematic review of economic analyses of transport and policies including health effects related to cycling and walking. The mean BCR for the studies they included was 5:1 with a range from -0.4 to 32.5. There was no systematic relationship between quality of the study and BCR. They identified a series of studies in which an incorrect assumption (9% of deaths attributed to physical inactivity, not 9% of all deaths) led to a significant underestimation of the value of cycling.

Rutter (2005, cited in Cavill et al., 2008) undertook a cost-benefit analysis to estimate the economic and other benefits of achieving cycling targets set for London.

Genter et al. (2008) values the crash costs for all cyclists (new and continuing) at 0 c/km and the health benefits at 16 c/km. It also includes estimates of the value of motorised traffic reductions, user cost savings, and environmental benefits. It notes that there can be benefits in terms of community liveability and consumer travel options but does not provide values for these. Genter et al. (2008) note that the EEM2 does not consider the benefits associated with exercise time savings (for already active new users), improved health for existing pedestrians and other active mode users (skates and scooters), parking cost savings, noise reduction and potential increases in work productivity (e.g. fewer sick days).

The NSW Government commissioned a cost-benefit analysis of completing nine major missing links of the Sydney Metropolitan Cycle Network (PricewaterhouseCoopers, 2009). In its estimated impacts of cycling per bicycle kilometre travelled (see Table 1), positive and negative health effects comprised a very small part of the overall net benefit. The overwhelming impacts related to decongestion benefit and savings in user cost.

Table 1. Estimated impact of cycling per bicycle kilometre travelled (Table 1 from PricewaterhouseCoopers, 2009).

Type of impact	Benefit (2008 c/bicycle km)
Decongestion benefit	24.28
Savings in user cost	16.39
Parking cost savings	1.00
Travel time costs	0.00
Bicycle crash cost	-2.03
Health benefits	1.42
Air pollution reduction	1.73
Noise reduction	0.85
Infrastructure provision	3.91
Greenhouse gas reduction	0.66
Total Net Benefit	48.22

Several authors (Saelensminde, 2004; Pucher & Buehler, 2008 etc) address the issue that the success of cycling facilities or participation might rely on "anti-auto" policies being implemented. Saelensminde (2004) discusses the "barrier costs" caused by motorised traffic preventing people from cycling or walking as much as they would prefer. These barrier costs are relatively high, about AUD0.2 per motorised journey and Saelensminde argues that they need to be incorporated in evaluating different kinds of restrictions on car use.

It should be noted that none of the cost benefit analyses appear to include the cost of non-crash cycling injuries (e.g. injuries of over-exertion such as sprains and strains).

Wegman (2010) also noted that a transfer from public transport to cycling or walking may have economic benefits because of the possible reductions in the need to provide subsidies to public transport.

2.5 Conclusions regarding effects of cycling on health

Cycling has the potential to improve health by providing needed physical activity. Approximately 70% of Australians undertake insufficient weekly levels of physical activity which is associated with a number of chronic health conditions. Guidelines for amounts of physical activity necessary for good health specify total duration, minimum duration of each bout and intensity. A 10km bicycle commute to work twice a day has been shown to improve fitness and HDL cholesterol levels. The annual health benefit of active travel by bicycle has been estimated at approximately $3,500 for each new person, and half that value for continuing commuters (Genter et al, 2008).

However, cycling exposes riders to the risk of injury and to the potential for respiratory disease related to air pollution. Cycling fatality and injury rates vary considerably among countries, being lowest in countries with well-developed cycling infrastructure and high cycling participation. In countries with low cycling participation (such as Australia) the fatality rate per distance travelled is about 14 to 28 times higher than travelling in a car, although estimates of distances travelled by bicycle may not be reliable. Injury rates are more difficult to estimate because many low severity injuries are not treated and many on-road crashes are not reported to Police.

The riding environment affects rider safety. The evidence suggests that clearly-marked, bicycle-specific facilities (including cycle tracks at roundabouts, bike routes, bike lanes and bike paths) are safer than on-road cycling with traffic or off-road with pedestrians and other users. Bicycle crashes on rural roads are often more serious because of the higher average vehicle speeds and lack of bicycle infrastructure. Off-road cycling is both popular and a significant contributor to bicycle-related trauma.

Pucher, Dill and Handy (2010) conclude that "the combined evidence presented in these studies [from countries without universal helmet legislation] indicates that the health benefits of bicycling far exceed the health risks from traffic injuries, contradicting the widespread misperception that bicycling is a dangerous activity" (p.S106). Our conclusion differs somewhat: cycling does have significant health benefits and therefore should be encouraged in ways that reduce the risk of the most serious of injuries. Head injuries not only have the potential for death but that they are among the most disabling of non-fatal injuries (in some ways more than spinal injuries). Infrastructure and speed management approaches to improving the safety of cycling should be undertaken as part of a Safe System approach, but protection of the individual by simple and cost-effective methods such as bicycle helmets should also be part of an overall package of measures.

3. BICYCLE HELMET LEGISLATION

This section reviews the literature regarding:

- The effectiveness of bicycle helmets in preventing injury, including an examination of head versus facial injuries;
- The types of bicycle helmet legislation enacted worldwide;
- The effects of bicycle helmet legislation on bicycle helmet wearing;
- The effects of bicycle helmet legislation on head injuries; and,
- The effects of bicycle helmet legislation on cycling participation.

In addition to estimates of cyclist volumes, the final section includes an examination of any reported disincentives to cycling from compulsory helmet wearing by analysing attitudinal surveys (WAVE) and other available attitudinal data from Queensland and other jurisdictions.

3.1 The effectiveness of bicycle helmets in preventing injury

> *"Although it makes inherent sense that helmets would be protective against head injury, establishing the real-world effectiveness of helmets is important"* (Thompson, Rivara & Thompson, 2009, p.1).

The Australian Standard for bicycle helmets requires that the headform sustains less than 400g radial acceleration in an impact from a 1.5m drop height. This impact is equivalent to an impact with a fixed object at a speed of 19.5km/h, or a Δv=5.4m/s (McDermott, 1995). The latest Australian Standard removed the requirement of bicycle helmets to pass a penetration test.

A Cochrane Review has examined "whether bicycle helmets reduce head, brain and facial injury for bicyclists of all ages involved in a bicycle crash or fall" (Thompson et al., 2009, p.1). Cochrane Reviews seek to identify research that has been conducted to the most rigorous scientific standards and to draw conclusions from this research. In the case of bicycle helmet research, the reviewers included only:

> *"Controlled studies that evaluated the effect of helmet use in a population of bicyclists who had experienced a crash. We required studies to have complete outcome ascertainment, accurate exposure measurement, appropriate selection of the comparison group and elimination or control of factors such as selection bias, observation bias and confounding"* (p.1)

> *"In order to be included in this review, we required that studies ascertain cases prospectively and identify and validate all injuries from medical records. We also required determination of exposure (helmet use) at the time of the bicycle crash, appropriate selection of the control group and elimination or control of factors such as selection bias, observation bias and confounding. Studies selected had to have equal ascertainment of exposure for case and control groups. Additionally, controls should be selected from the same population from which the cases were derived"* (p.2)

This resulted in five studies that examined the effects of bicycle helmets on head injuries (Thompson, 1996; Maimaris, 1994; Thomas 1994; McDermott, 1993; Thompson, 1989) and three studies that examined the effects of bicycle helmets on facial injuries (Thompson, 1996a; McDermott, 1993; Thompson, 1990) being included in the Cochrane Review. The review also includes a detailed presentation of arguments by critics who disagree with the conclusions reached by the review and the replies by the authors.

The authors note that head injury is by far the greatest risk posed to bicyclists, comprising one-third of emergency department visits, two-thirds of hospital admissions, and three-quarters of deaths. The Cochrane Review concluded that bicycle helmets, that meet national standards, do protect against head, brain, and facial injuries. This protective effect is present for cyclists of all ages, and for a variety of crash causes (Thompson et al, 2009). Across the studies reviewed, helmet wearing was associated with a 69% reduction in the likelihood of head injury, a 69% reduction in the likelihood of brain injury, and a 74% reduction in the likelihood of severe brain injury (controls sampled from emergency departments). The estimate of the size of the protective effect was larger if controls were sampled from the general population rather than from emergency departments. Helmet wearing reduced the likelihood of head injury by 69% in riders in crashes involving motor vehicles and 68% in all other types of crashes. Helmet wearing reduced the likelihood of injury to the upper and mid-face by 65%.

Case control research of emergency department presentations has shown that the risk of injuries to the upper part of the head was 2.7 times higher for children who were not wearing helmets at the time of their bicycle crash. Loss of consciousness was more than 7 times higher for non-helmet wearing children. This equates to a reduction in risk of 63% for upper head injuries and 86% for loss of consciousness when wearing a helmet. When facial injuries were also considered with upper head injuries, the protective effect of helmets for head injuries was reduced to 51%. It is important to note that significantly more children with an upper head injury had crashes that involved contact with another moving vehicle (Thomas et al, 1994).

Research in the United Kingdom has compared injury patterns for helmet wearing and non-helmet wearing cyclists (Maimaris et al, 1994). Results demonstrated that there was no significant difference in body regions injured, or the nature of injury except for head injuries. When comparing head injuries, only 4% of helmet wearing cyclists suffered head injuries compared with 11% for non-helmet wearing cyclists.

Research from Canada examining bicycle fatalities found that the vast majority involved bicyclists not wearing a helmet (96%), although some fatalities did involve helmeted cyclists (Rowe et al, 1995). The majority of fatalities involved collisions between motor vehicles and bicycles. This is supported by additional research conducted in the United States (Nicaj et al, 2009).

A Melbourne study (McDermott, 1995) provides a detailed analysis of the first object struck by the bicyclist, and the first object struck by the head (or helmet). Bicyclists were most likely to make first contact with the ground (30.5%), followed by fixed objects (12.2%) and motor vehicles (6.4%). There was no difference in objects struck for those wearing an approved helmet and those not wearing a helmet. In almost half of the cases (46%), bicyclist casualties did not strike their head against any object. In 30% of cases the head first made contact with the ground, while in another 15% of cases the first contact point was a motor vehicle (McDermott, 1995). When fatalities were considered, helmet wearing cyclists had fatality rate of 0.4% while unhelmeted riders had a fatality rate of 0.9%. However this finding was not significant. Head injuries were less frequent, and less severe, for helmet-wearing bicyclists. This trend was also observed for facial injuries. Neck injuries were also examined, and the frequency of neck injuries significantly increased for the helmet wearing group (McDermott, 1995). Self-report data also supports the finding that bicycle helmets offer protection against head injuries (Wasserman et al, 1988).

Research from the US (Wesson et al, 2008) examined the protective capacity of bicycle helmets against serious facial injuries (i.e. fractures and lacerations). Bicycle helmets were shown to significantly reduce the risk of lacerations or fractures to the upper face (forehead, orbit, eyes and ears) and mid face (nose and cheeks), while having no significant effect on the risk of injury to the lower face (lower jaw, lips and mouth) (Thompson et al, 1996). This research states that injuries to the lower face can also have serious, long-term implications. The authors suggest modifications to current helmet designs to provide protection to the lower face.

While cycling risk (rate per million kilometres travelled) appears high when compared with other forms of transport, there are fewer cyclist deaths in absolute numbers. Fatalities of pedal cyclists are usually a result of head injuries sustained following a collision with a motor vehicle. McCarthy (1991) concludes that bicycle helmets may provide a protection against head injuries resulting from a fall; but that the protective effect of helmets in impacts with motor vehicles is less established. On the basis of a range of studies (many of which post-dated McCarthy's study), the Cochrane Review cited earlier (Thompson et al., 2009) concluded that bicycle helmets are equally effective in preventing head injury in motor vehicle involved bicycle crashes and those that do not involve motor vehicles.

Research from New Zealand compared the protective effects of bicycle helmets for non- motor vehicle and motor vehicle bicycle crashes. In non motor vehicle bicycle crashes, cyclist head injuries decreased with increasing helmet wearing rates. This was evident across age groups, being strongest among children of primary school age. This trend was also found for bicycle crashes involving a motor vehicle, although the effect was not as great. The differences in protectiveness of helmets across ages may reflect differences in the crash characteristics at different ages. Changes in hospital admission policies did not appear to influence the decrease, with no concurrent decrease in head injury hospitalisations for non-cyclists (Povey et al, 1999).

Research from Singapore has also investigated cyclist injuries and helmet use. Data from acute injury presentations indicate that not wearing a helmet is significantly associated with higher injury severity scores. Not wearing a helmet is also associated with greater risk of head and facial injuries (Heng et al, 2006).

While the majority of research supports the hypothesis that bicycle helmets are effective at preventing head injuries, this position is not universally supported. Some research questions the applicability of current standards to particular riding locations (e.g. riding off road), while others question new helmet designs.

It is acknowledged that the nature of mountain biking differs significantly from conventional bicycling, and cases are noted where serious injuries are sustained despite the helmet being worn (and remaining attached to the head). Helmet standards require that the helmet should protect a rider from impacts up to 24km/h with a flat surface. However, speeds attained while mountain biking, and conventional cycling, can far exceed this benchmark. Speeds in excess of 72km/h have been recorded in downhill mountain biking races (Chow et al, 1995).

Some researchers have questioned the applicability of early helmet research to current situations and the appropriateness of assumptions underlying the tests to which helmets must conform to meet national standards. Curnow (2003) notes that helmet designs were originally hard-shell, later changing to soft helmets (no shell) or micro-shell (thin shell) designs with more holes for ventilation. He also describes four types of head injuries: focal; closed, angular (rotational); and diffuse. Early accepted wisdom was that linear acceleration was the dominant cause of brain injury; however it is now acknowledged that angular (rotational) acceleration is more important. Despite this, helmet standards continue to test only for linear acceleration (Curnow, 2003). It is also noted that angular acceleration, and brain injury, can occur even when the head has not been struck.

Other researchers have concluded that bicycle helmets should not be the sole focus in decreasing cycling-related morbidity (Davidson, 2005) and that steps should also be taken to improve the safety of road infrastructure and reduce speeds of motorised traffic.

There is some research to suggest that drivers behave differently when cyclists are wearing helmets. Research from the United Kingdom, with no compulsory helmet legislation, has shown that motorists pass closer to cyclists wearing helmets (Walker, 2007) because helmets are associated with more skilled cyclists. In contrast, in the Netherlands, where helmets are not mandatory and wearing rates are extremely low (except in competitive cycling), it has been stated that motorists will assume that a cyclist wearing a helmet is a foreigner and therefore likely to behave erratically and so motorists will act carefully (Aland, 2010). There is no evidence of such differences in driver behaviour as a function of cyclist helmet use in jurisdictions where bicycle helmet use is mandatory.

3.2 The types of bicycle helmet legislation enacted worldwide

3.2.1 Australian legislation

Legislation has been enacted in all Australian Territories, making the wearing of bicycle helmets compulsory. This legislation is outlined in the Australian Road Rules:

Part 15, Section 256 Bicycle helmets

(1) The rider of a bicycle must wear an approved bicycle helmet securely fitted and fastened on the rider's head, unless the rider is exempt from wearing a bicycle helmet under another law of this jurisdiction.

(2) A passenger on a bicycle that is moving, or is stationary but not parked, must wear an approved bicycle helmet securely fitted and fastened on a passenger's head, unless the passenger is:

  a. A paying passenger on a three or four-wheeled bicycle; or

  b. Exempt from wearing a bicycle helmet under another law of this jurisdiction.

(3) The rider of a bicycle must not ride with a passenger on the bicycle unless the passenger complies with subrule (2).

The bicycle helmet legislation applies on all roads (including shoulders and footpaths) and road-related areas which include:

- An area which divides a road;
- A footpath or nature strip adjacent to a road;
- An area that is not a road but is open to the public and designated for use by cyclists or animals; and,
- An area that is not a road that is open to, or used by, the public for the purpose of parking vehicles.

3.2.1.1 Queensland

In Queensland, the helmet wearing legislation came into effect on 1 July 1991 and was accompanied by widespread publicity. There was no penalty for not wearing a helmet and no enforcement system. A six month review of the effects of the legislation (Dix & Dreves, 1992, cited in King & Fraine, 1994) found that helmet wearing rates increased substantially immediately after the legislation was introduced but reduced after that. A system of bicycle offences was developed and the penalty and enforcement system took effect from 1 January 1993, with a waiver provision applying for the first six months. Under the waiver provision, the penalty for failing to wear a helmet ($30 – set at the approximate cost of a helmet) was waived if the offender showed evidence of having purchased a helmet within 14 days of the offence (King & Fraine, 1994). The current penalty for not wearing a bicycle helmet is a fine of $100, equivalent to the fine for failing to give way to a bus or failing to stop at a school crossing (TORUM, 2010). Newspaper reports suggest that approximately 7,500 fines are issued to Queensland cyclists each year for failure to comply with helmet legislation (Courier Mail, 2010).

In Queensland, a rider or a pillion is exempt from wearing a bicycle helmet if they are carrying a current doctor's certificate that states that, for a stated period, they cannot wear a bicycle helmet for medical reasons or that because of a physical characteristic of the person, it would be unreasonable to require them to wear a bicycle helmet.

3.2.1.2 Northern Territory

All State and Territory road rules conform to the national road rules, except for the Northern Territory where a variation allows adult bicycle riders travelling on separate bicycle paths and footpaths to travel without wearing a bicycle helmet. The details of the legislation are provided below:

Northern Territory Traffic Regulations, Section 86

(1) For the purpose of rule 256, the requirement to wear an approved bicycle helmet does not apply to a person over 17 years of age if he or she is riding or being carried on a bicycle;

  a. on a public place;

  b. on a bicycle path or shared path; or,

  c. is in an area declared by the Minister, by notice in the Gazette, to be a bicycle helmet exemption area.

(2) In this regulation, a bicycle path does not include a bicycle lane that is not separated from the part of the road used by motor vehicles by a physical structure or barrier in addition to or in substitution for the lane line.

(3) In this regulation and rule 256, an approved bicycle helmet is a helmet that:

  a. complies with Australian Standard AS/NZS 2063:1996 – Pedal Cycle Helmets; or

  b. is approved by the registrar.

3.2.2 International legislation

3.2.2.1 New Zealand

Bicycle helmet legislation in New Zealand is similar to the Australian Road Rules, but allows helmets complying with a range of international standards and relates to on-road use only. The New Zealand legislation is detailed below:

Land Transport (Road User) Rule 2004, Part 11

11.8 Safety helmets for cyclists

(1) A person must not ride, or be carried on, a bicycle on a road unless the person is wearing a safety helmet of an approved standard that is securely fastened.

(2) The approved standards for safety helmets are–

  a. AS/NZS 2063, Pedal Cycle Helmets; or

  b. NZS 5439, Pedal Cycle Helmets; or

  c. AS 2063.2, Pedal Cycle Helmets; or

  d. Any safety helmet manufactured to the Snell standard for protective headgear for use with bicycles; or

  e. Any safety helmet manufactured to ASTM F1447; or

  f. Any safety helmet manufactured to the Consumer Product Safety Commission Safety Standard for Bicycle Helmets (reference 16CFR) Part 1203, complying with the CPSC certification process.

(3) A safety helmet must comply with the version of an approved standard for safety helmets that is–

  a. Applicable in the relevant standard-setting jurisdiction to the date of manufacture of the safety helmet or as specified in the standard; or

b. A more recent version of the standard if the safety performance of the safety helmet is not adversely affected.

(4) An approval of a safety helmet under the Traffic Regulations 1976 that was published in the Gazette before 27 February 2005 remains valid after this rule comes into force

(5) A person riding a cycle that is towing a trailer must ensure that every person carried on the trailer is wearing a safety helmet of an approved standard that is securely fastened.

(6) A person riding, or being carried on, a cycle on a road who is stopped by an enforcement officer must, if so requested by that or any other enforcement officer, produce for inspection by the officer the person's safety helmet or proof of exemption granted under subclause (7).

(7) Subclauses (1) and (5) do not apply to a person if the Agency grants the person a written exemption from the requirement to wear a safety helmet on the grounds of religious belief or physical disability or other reasonable grounds.

(8) The Agency may at anytime revoke in writing an exemption granted under subclause (7).

(9) The Agency may, by notice in the Gazette, approve types of safety helmets for use under this clause.

(10) In proceedings for an offence of breaching this clause, proof that a safety helmet worn by the defendant did not bear a standard specification mark or registered trademark is, until the contrary is proved, sufficient evidence that the helmet was not of an approved standard.

3.2.2.2 United States

There is no federal legislation in the United States of America requiring the use of bicycle helmets. However, several states and localities have implemented compulsory bicycle helmet legislation, mostly for children under the age of 16 years.

3.2.2.3 Canada

Compulsory bicycle helmet legislation exists in five Canadian provinces: British Columbia, Ontario, Halifax, New Brunswick, Alberta and Nova Scotia. Bicycle helmet wearing is compulsory for all ages in British Columbia, Halifax, New Brunswick and Nova Scotia, while helmets are only compulsory for riders aged less than 18 years in Ontario and Alberta.

3.2.2.4 Finland

A mandatory bicycle helmet law for all ages is in effect in Finland but there is no fine associated with failing to comply.

3.2.2.5 Spain

It is compulsory to wear a helmet in Spain when cycling outside of cities. Helmets are not compulsory when cycling in towns, and may also be removed when climbing steep hills.

3.2.2.6 Iceland

A mandatory helmet law is in place for cyclists under the age of 16 in Iceland.

3.2.2.7 Czech Republic

Helmet wearing is compulsory for cyclists under the age of 16 in the Czech Republic.

3.2.2.8 Japan

Under a national law, it is compulsory for cyclists under the age of 13 to wear bicycle helmets.

3.3 The arguments against compulsory helmet wearing

In 1999, the British Medical Association's (BMA) Board of Education and Science concluded that "cyclists are advised to wear helmets but legislation to make them compulsory is likely to reduce the number of people choosing to cycle and would not be in the in interests of health" (Carnall, 1999, p.1505). The BMA cites data on the reduction in cycling in the year after the introduction of legislation in Victoria. It also notes that promotion to increase the current low level of voluntary helmet use would be needed before legislation could be effective in Britain and that some cyclists oppose wearing helmets. It claims that more lives would be saved by encouraging pedestrians and car occupant to wear helmets. It claims that pedestrians and cyclists form a smaller proportion of casualties in the Netherlands and Denmark where helmets are not required, but reductions in speed limits and separate cyclist infrastructure have been implemented. The BMA states that helmets may be more protective in a fall than in a collision with a vehicle, that children are more likely to fall off bicycles and therefore helmets may provide more benefits for children. It recommends that government should consider subsidising helmets and promoting helmets manufactured to the Snell standard. In addition, the BMA recommends that children should receive cycling training and awareness of cyclists and other road users should be included in the driving test.

Other critics have posited additional arguments against the effectiveness of helmets in preventing injury. Some have argued that the lower severity of injury to riders wearing helmets reflects that this sub-group of riders were safer riders in other ways (reviewed by Robinson, 1996). In contrast, other critics have argued that risk compensation occurs, and riders who wear helmets will take more risks and therefore be injured more (Hillman, 1993; Adams & Hillman, 2001). Robinson (1996) and others have argued that head injuries were decreasing before legislation was introduced (because of other road safety measures) and so the reductions reflect this ongoing trend, not the effectiveness of helmets. Robinson (1996) comments that a reduction in cycling as a result of helmet wearing legislation may increase risk for individual cyclists by a reverse of the "safety in numbers" hypothesis (Jacobsen, 2003).

Another argument put forward by opponents of helmet wearing legislation is that it "may distract attention from more effective means of reducing the number and severity of cycling accidents" (BMA, 1992, p.87) , including reducing speed limits and traffic calming, enforcement of driver behaviour, better cyclist infrastructure and improvements to the visibility of cyclists.

3.4 Benefit-cost analyses for compulsory helmet laws

A number of studies have examined the cost effectiveness of bicycle helmet legislation.

Taylor and Scuffham (2002) compared the costs associated with purchase of helmets with the value of the injuries (but not deaths) prevented by helmets. The injuries prevented were taken from an earlier analysis of the effects of the first 3 years of the legislation (Scuffham, Alsop, Cryer et al., 2000). These were valued according to willingness to pay estimates to avoid injuries requiring hospital stays of less than seven days or seven days or more. It was assumed that all unhelmeted riders before the law were required to buy a new helmet (social cost about $NZ18 each) and that the helmet life was 5 years. They concluded that the cost effectiveness of the helmet law was greatest for 5-12 year olds (2.61:1), with a BCR of 0.85:1 for 13-18 year olds and 0.74:1 for adults. Taylor and Scuffham undertook a number of different analyses that assumed different scenarios (e.g. high and low helmet effectiveness, with and without cost of enforcement, with and without people quitting cycling instead of wearing a helmet). They report that there results were sensitive to many of these assumptions (particularly helmet cost and helmet life). They note that their estimates of the benefits are likely to be too low because they do not include the very high costs associated with permanently disabling head injuries, the value of preventing minor (non-hospitalised) injuries, and increased visibility.

3.5 The effects of bicycle helmet legislation on bicycle helmet wearing

3.5.1 Australian research

Research in several Australian states has evaluated the effects of helmet wearing legislation on helmet wearing rates.

As described earlier, helmet wearing legislation came into effect in Queensland on 1 July 1991 with penalties and enforcement from 1 January 1993 (with a waiver for the first six months if show purchase of a helmet within 14 days). Introduction of the legislation was associated with increases in helmet wearing rates when measurements taken in April and September 1991 were compared (primary school students: 59% then 85%, secondary school students: 13% then 38%, commuter cyclists: 21% then 52%, recreational cyclists: 22% then 46%) (King & Fraine, 1994). Following introduction of the penalties and enforcement, there was little increase in wearing rates by primary school students but wearing rates of secondary school students, commuter cyclists and recreational cyclists increased to 61%, 80% and 71%, respectively (in October 1993). The report noted that many secondary school students who were not wearing a helmet were actually carrying it, so helmet availability does not necessarily translate to helmet use.

The RACQ also conducted a series of bicycle helmet wearing surveys that commenced in 1988 and continued until 2001 (Traffic and Safety Department, 2001). As shown in Table 2 below, the overall helmet wearing rates (across all age groups and surveyed areas of Queensland) ranged from 11% to 16% in the years before the legislation was introduced. The overall helmet wearing rate jumped to 52% in 1991 when the legislation was introduced and then it increased to 71% in 1997 and 77% in 2001. Introduction of the penalty appeared to be associated with an increase in wearing rates by secondary school students and a smaller increase for adults. Wearing rates were maintained or increased from 1997 to 2001.

The cycling section of the Queensland Sustainable Transport Survey 2010 (described in more detail later) reports the average number of times per year that respondents who owned bicycles reported cycling in the years 2001-10. Of the WAVE Survey population in 2010, 35.2% (144) indicated that they cycle at least once per year and 89% of these respondents reported they always wear a helmet when cycling (MCR, 2010). The 2010 reported helmet wearing rate was somewhat less than in 2006 to 2009 (93 and 94%), but a little higher than in 2003-2005 (where it ranged from 73 to 85%). Over the period 2006 to 2010, wearing rates were higher for females than males and higher for riders aged over 30 than under 30.

Observational data from other States have shown much higher rates of helmet wearing before and immediately following the introduction of the law. The enactment of mandatory bicycle helmet wearing legislation in Victoria in July 1990 was preceded by ten years of promotion,

Table 2. Percent of cyclists observed wearing helmets. RACQ surveys.

Age group	1990	1991	1997	2001
Primary school students	43	84	84	88
Secondary school students	10	38	66	67
Adults	-	55	72	91
Children at other locations	-	36	70	80
All cyclists	16	52	71	77

involving education, mass media publicity, support by professional associations, and community groups, consultation with bicycle groups, and financial incentives (Carr, Skalova & Cameron, 1995). While helmet wearing rates for bicyclists in Victoria had been steadily increasing from around 5% in 1982/83 to 31% in 1989/90, after the legislation was introduced there was a dramatic increase to 75% in March 1991 (Cameron, Heiman & Neiger, 1992). The law achieved its goal of increasing helmet wearing rates for all age groups of bicyclists although wearing rates by teenagers remained lower than for children than adults (Finch, Heiman & Neiger, 1993, TTM Consulting Pty Ltd, 1994, see Table 3).

3.5.2 International research

Helmet wearing rates in jurisdictions where there is universal helmet legislation, legislation only for children and where there is no legislation (or rates collected before the introduction of legislation) are summarised in Table 4.

A Cochrane Review examined the effect of compulsory helmet legislation on helmet wearing and head injuries (see description of Cochrane Reviews in Section 3.1). It concluded that legislation corresponded with an increase in bicycle helmet wearing rates (Macpherson & Spinks, 2009). A similar review, although using different inclusion criteria, also reached the same conclusions (Karkhaneh et al 2006).

New Zealand bicycle helmet wearing rates have been monitored from 1990 to 2010 by the New Zealand Ministry of Transport. Prior to the introduction of compulsory helmet wearing legislation, adult wearing rates were approximately 30%, while the rate for primary school children was approximately 65%. After the legislation, wearing rates increased to about 95% for children and 90% for adults (Robinson, 2001). These high rates of helmet wearing have been sustained (http://www.transport.govt.nz/research/cyclehelmets2009/).

The effect of bicycle helmet legislation on helmet wearing has also been examined in Canada and the United States. In the Canada and the United States no national legislation has been implemented, with legislation generally state- or locality- based, and mostly only for children.

Table 3. Melbourne metropolitan helmet wearing rates. Source: Finch, Heiman & Neiger (1993), TTM Consulting Pty Ltd (1994).

	Pre-law (1987)	Post-law (1991)	Post-law (1992)	Post-law (1994)
Children (5 to 11 years)	65%	78%	78%	83%
Teenagers (12 to 17 years)	21%	45%	59%	61%
Adults (18+ years)	36%	74%	84%	96% 80% (1)

(1) 96% at commuter sites and 80% at recreational sites

Multiple approaches were used to investigate the effect of a state-wide bicycle helmet law in Oregon, US. All measures demonstrated an increase in bicycle helmet use. Observational results across 13 sites demonstrated an increase from 24.5% pre-legislation to 49.3% post-legislation. Self-report data from almost 1000 students demonstrated an increase in "always wear a helmet" from 14.7% to 39.4% (Ni et al, 1997).

Howard County in the US state of Maryland was the first US jurisdiction to mandate helmet use for children from 1 October 1990 (Coté et al, 1992). The effect on helmet wearing rates was examined in an observational study that collected data on one day about three months prior to the legislation and one day about six months after the legislation. This research found that there was an overall increase in helmet wearing by children from 4% to 47%. The increase was larger on roads than in parks or outside schools and larger for females than males (Coté et al, 1992). *See Table 4.*

An evaluation of the effect of child bicycle helmet laws in Florida counties was conducted. Children's use of helmets when riding to school was measured. Rates of helmet use were compared between counties with helmet laws, and those who opted out. In counties where a compulsory helmet wearing law was in place, helmet wearing rates were 79%. Where helmet laws were not in place, only 33% of children bicyclists wore a bicycle helmet (Kanny et al, 2001).

A long-term investigation of helmet wearing rates of children was conducted in Broward County, Florida which examined changes in behaviour following compulsory helmet legislation. Prior to legislation, only 3.7% of elementary school children wore helmets, and 0% of middle school children were observed wearing a bicycle helmet. Four years after the introduction of helmet wearing rates had increased significantly. The rate had increased to 71.5% for elementary aged children, and 22% for middle school children (Delamater, 2003). In a similar long-term study conducted in Hillsborough County, Florida, similar results were found. This research was not segmented across age groups, but did find that prior the legislation helmet use was 3.6% and increased to 50.1% four years after the introduction of the compulsory helmet law (Liller et al, 2003).

Prior to the introduction of compulsory bicycle helmet wearing legislation for all ages in British Columbia, there were relatively high helmet wearing rates of approximately 50%. Helmet wearing rates increased to approximately 75% over the three years following the introduction of the legislation. Compliance rates prior to legislation varied according to gender (females more likely to wear a helmet), as well as type of cycling (commuter, recreational or neighbourhood cycling). However, following legislation, compliance rates were similar (Foss et al, 2000). While there were lower rates of pre-legislation helmet wearing in Halifax (40%), post-legislation helmet-wearing rates increased to 75% in a year and 86% after two years (LeBlanc et al, 2002).

The presence of alcohol also affects the likelihood of bicyclists wearing helmets. International research has shown that bicyclists who are injured in crashes while under the influence of alcohol are significantly less likely to wear a helmet (Anderson & Bunketorp, 2002; Crocker et al, 2010; Li et al, 1996). As a result of the reduced helmet wearing rates of intoxicated riders, they are at a greater risk of injury to the head or face (Anderson & Bunketorp, 2002).

3.6 The effects of bicycle helmet legislation on head injuries

3.6.1 Australian research

King and Fraine (1994) compared crash and head injury data prior to the introduction of helmet wearing legislation in Queensland ("before"), during the period in which there was legislation but no penalty ("interim") and after the penalty was introduced ("after"). The mean quarterly numbers of cyclist crashes resulting in fatality or hospital treatment fell from 82.2 in the before period to 70.5 in the interim period to 57.3 in the after period. Similar changes were observed in the numbers of cyclist in crashes classed as "Other Medical Treatment".

Table 4. Summary of helmet wearing rates across jurisdictions with mandatory universal laws, mandatory laws for children only and no mandatory requirement (or before legislation).

Jurisdiction	Helmet-Wearing (%)	Characteristics	Year sampled	Reference
MANDATORY UNIVERSAL				
Finland (no penalty for non-compliance)	14% (overall) 39% (Southern Finland)	Whole of Finland, further information not available	1998	Lajunen et al (2001)
British Columbia, Canada	75% (commuters) 74% (recreational) 72% (neighbourhood) 60% (community sample)	Population-based survey from 17 communities, including cyclists from all age groups		Foss & Beirness (2000)
Halifax, Canada	75% 86%	Population-based survey from metropolitan areas	1997 (1 year after legislation) 1998(2 years after legislation)	LeBlanc et al (2002)
Melbourne, Australia				
New Zealand	95% (children) 90% (adults)	Population-based survey from all New Zealand localities, including cyclists from all age groups	Annually since 1995	
MANDATORY CHILDREN				
Oregon, USA	49% (state-wide) 49% (Portland) 50% (Large city) 49% (Small town)	State law for children under the age of 16. State-wide observational data (July to September)	1994	Ni et al (1997)
Howard County, Maryland, USA	47%	State law for children under the age of 16. Sample collected for a single day	1991	Coté et al (1992)
Florida (state-wide)	79%	State law for children under the age of 16		Kanny et al (2001)
Broward County, FL, USA	72% elementary aged children 22% middle school aged children	State law for children under the age of 16		Delamater (2003)
Hillsborough County, FL, USA	50%	State law for children under the age of 16. Sample of school aged children		Liller et al (2003)

In order to assess whether this reduction in crashes may have represented a reduction in riding, rather than an improvement in safety, data on head injuries and other injuries provided by the Queensland Injury Surveillance and Prevention Program (QISPP) from a sample of hospitals in the southern part of Brisbane were analysed. The percentage reductions in head injuries (both admitted to hospital and treated at emergency department only) from the before to the interim to the after periods were greater than the percentage reductions in total injuries to other parts of the body. King and Fraine (1994) conclude that on the basis of these data, it appears that the introduction of the helmet legislation (without a penalty) reduced cyclist severe (defined as admitted) head injuries by 26% more than expected if they had followed the trend for other injury types (with a 15% reduction for treated head injuries). The addition of the penalty for non-compliance had a larger effect, reducing severe head injuries by a further 55% and less severe injuries by a further 8% compared with the expected values. Thus, helmet wearing legislation and enforcement was associated with a reduction in head injuries that could not be explained as an effect of less cycling.

The effect of the Victorian bicycle helmet laws on bicyclist head injuries has been examined in a series of studies. This research found that the number of bicyclists admitted to hospital with head injuries decreased following the introduction of compulsory helmet-wearing. From 1986/87

Table 4 (continued). Summary of helmet wearing rates across jurisdictions with mandatory universal laws, mandatory laws for children only and no mandatory requirement (or before legislation).

Jurisdiction	Helmet-Wearing (%)	Characteristics	Year sampled	Reference
NOT MANDATORY/ PRIOR TO MANDATORY				
Netherlands	2% (cycling for transportation) 18% (cycling for recreation)	Attendees of the Dutch Paediatric Society	2006	Villamore et al (2008).
England	36.8% (year 6 children) 13.7% (year 10 children)	Self-report data from two high schools and four primary schools	1995	Wardle & Iqbal (1997)
British Columbia, Canada	60% (commuter) 48% (recreational) 39% (neighbourhood) 39% (community sample)	Population-based survey from 17 communities, including all age groups	Before legislation 1995	Foss & Beirness (2000)
Halifax, Canada	 36% 38%		Before legislation 1995 1995	LeBlanc et al (2002)
Oregon, USA	24.5% (state-wide) 27.3% (Portland) 25.8% (Large city) 20.0% (Small town)	State law for children under the age of 16. State-wide observational data (July to September)	Before legislation 1986-1993	Ni et al (1997)
Howard County, Maryland, USA	4%	State law for children under the age of 16. Sample collected for a single day	Before legislation for children 1990	Coté et al (1992)
Florida (3 counties)	33%			Kanny et al (2001)
Broward County, FL, USA	3.7% elementary aged children 0% middle school aged children		Before legislation for children	Delamater (2003)
Hillsborough County, FL, USA	3.6%	School-aged children	Before legislation for children	Liller et al (2003)
New Zealand	65% (children) 30% (adults)	Population-based survey from all New Zealand localities, including cyclists from all age groups	1990-1993	

to 1989/90 there were between 400 and 500 bicyclists admitted to public hospitals in Victoria with head injuries. After the legislation was introduced this fell to around 250 (Cameron, Heiman & Neiger, 1992). After the legislation was introduced the number the number of severe bicyclist casualties with head injury registered with the TAC fell to around 50 in 1990/91 and 35 in 1991/92 (Finch, Newstead, Cameron & Vulcan, 1993) (approximate figures derived from graph). These decreases were associated with an increase in helmet wearing rates, coupled with reduced levels of cycling. Likewise there was a reduction in the number of cyclists killed with a head injury. These reductions represented a considerable saving each year, for example a reduction of 40 severe head injuries (assuming $408,000 each) per year translated to savings of just over $16m per year.

Statistical modelling estimated that in the four years following the introduction of the legislation there was a 39.5% reduction in the head injury hospital admissions in Victoria (Carr et al, 1995). Helmet legislation was shown to account for a large proportion of the reduction, although the researchers acknowledge some of the reduction may be a result of a reduction of exposure to crash risk. While the number of head injuries recorded was reduced, the proportion of bicyclists admitted with critical head injuries was unchanged following the introduction of bicycle helmet legislation. However, there was a reduction in the serious and severe head injuries to bicyclists (Carr et al, 1995).

3.6.2 International research

A Cochrane Review has examined the effect of compulsory helmet legislation on helmet wearing and head injuries (Macpherson & Spinks, 2009). The review examined six studies conducted in various jurisdictions that reported changes in either the number of head injuries or helmet use. To be included as part of the review, the research had to have featured a control group. The results of the included studies were expressed in terms of bicycle related mortality, head injury rates or helmet-wearing rates. The review concluded that there was a significant increase in bicycle helmet use following the introduction of legislation. It also found that there was decrease in mortality and head injuries (Macpherson & Spinks, 2009).

Research was conducted in New Zealand that examined the effect of voluntary bicycle helmet wearing rates on head injuries that resulted in hospital admission in the years leading up to the introduction of bicycle helmet legislation (Scuffham & Langley, 1997). This research found that an increase in voluntary helmet wearing rates from 1986 to 1992, with highest rates for primary school children, followed by secondary school age children, followed by adults. In one analysis, they compared the percentage of admitted patients with head injuries for cyclists versus non-cyclists. The percentage with head injuries decreased over time for both groups. A Poisson regression showed no difference in the incidence of head injuries to cyclists as a function of the increase in helmet wearing rates. The authors discuss the difference between their results and previous studies and speculate that bicycle helmets may be less effective in preventing injuries that result in hospital admission, than in injuries that result in emergency department presentations.

Research from Canada examined the trends in paediatric and adult cycling fatalities as a result of the introduction of a bicycle helmet law. Bicycle helmet legislation was introduced in Ontario, Canada for bicycle riders under the age of 16. The findings found a 52% reduction in the average number of deaths for bicyclists aged ≥15 years, and a 55% decrease in the mortality rate, following the introduction of the legislation. No significant changes were found for the average number of deaths, or mortality rate, for bicyclists aged 16 years or older (Wesson et al, 2008).

An examination of bicycle fatality rates in the United States demonstrated a steady reduction in fatality rates between 1975 and 2000, despite helmet legislation only being introduced in many states during the 1990's (although mainly for compulsory helmet wearing by children). During the same period, adult bicycle fatality rates have risen slightly.

Analysis of bicycle crashes in the Netherlands has highlighted the importance of bicycle helmets. The Netherlands is often hailed as the leading centre for cycling participation and safety. However, despite the advances in safety most notably the reduction in bicycle-motor vehicle collisions, data suggests there is a very high proportion of head and face injuries (SWOV). Of the 185 cyclist fatalities in the Netherlands in 2009, half of these were in crashes that did not involve a motor vehicle (Aland, 2010). It is likely that most of these fatalities could have been prevented by helmet wearing.

The cost-effectiveness of bicycle helmet legislation has been modelled for different ages of cyclists in New Zealand. The cost of purchasing a helmet (or quitting cycling) was compared with the number of deaths or injuries expected to be prevented over the life of a helmet. This research suggests that the average cost per life saved was approximately $100,000 for children, $750,000 for teenagers, and $950,000 for adults. For lower severity injuries, the cost per hospitalisation avoided was approximately $3,700 for children, $18,000 for teenagers and $52,000. It is important to note that the models are extremely sensitive to estimated efficacy value (Hansen & Scuffham, 1995).

3.6.3 Effects of repealing helmet legislation

There are few studies of the effects of repealing bicycle helmet legislation, possibly because organisations responsible for those decisions have no motivation to fund the research.

In contrast, there have been a very large number of studies of the effects of repealing (and sometimes reinstating) motorcycle helmet laws in the United States. A comprehensive review of these studies is beyond the scope and timeframe of this report, but the results are reviewed briefly here because they may provide an insight into the likely impact of repealing bicycle helmet legislation. Kentucky, Louisiana, Arkansas and Texas were among the first states to repeal their universal motorcycle helmet laws in the late 1990s (Ulmer & Preusser, 2003). In each of these States, the observed helmet wearing rate was between 97% and 100% before the law was repealed and it dropped to between 52% and 66% following the repeal. Evaluations from several states have shown that helmet wearing rates also dropped among injured young riders who were still covered by the legislation (Preusser, Hedlund &Ulmer, 2000; Ulmer & Northrup, 2005).

Increases in motorcycle riding and trauma across the United States in the last two decades have complicated the interpretation of increases in motorcyclist fatalities and injuries following repeals of universal helmet laws. However, the numbers of motorcyclists killed and injured per 10,000 registered motorcycles increased in many states following the changes in the laws. In Kentucky, the fatality rate in the two years following the repeal of the legislation increased by 37% (compared with the two years before the repeal) and the injury rate increased by 17%. In Louisiana, the fatality rate in the year following the repeal was 7% higher than in the two years prior to the repeal and the injury rate rose 20% (Ulmer & Preusser, 2003). In Arkansas and Texas, the proportion of injured riders with head injuries increased after the repeal of universal helmet laws (Preusser et al., 2000). In Florida, motorcyclist admissions for head injuries increased by 81% after the repeal of their legislation.

Reinstatement of universal motorcycle helmet laws appears to reverse previous changes. An evaluation of the reinstatement of the universal helmet law in Louisiana (Gilbert, Chaudhary, Solomon, Preusser & Cosgrove, 2008) found that helmet use in motorcycle crashes increased from 42% pre-reinstatement to 87% post-reinstatement. This was accompanied by a drop in fatal motorcycle crashes (not replicated in a nearby state which had not changed their legislation) and a reduction in the proportion of all motorcycle crashes which resulted in fatality or serious injury.

3.7 The effects of bicycle helmet legislation on cycling participation

Critics of mandatory helmet legislation claim that it led to an immediate reduction in cycling participation and that cycling participation continues to be suppressed by the legislation. In this section, the available data are reviewed to assess whether the initial effect occurred and whether cycling participation continues to be reduced. The data are of two types – measures of actual or self-reported riding and attitudinal data regarding barriers to cycling.

3.7.1 Measures of actual or self-reported riding

Unfortunately, there is a lack of systematic long-term measures of cycling participation that provide an unbiased measure of participation in cycling across a whole range of purposes and locations. Much of the longer-term data relates only to cycling to work but people ride bicycles for a number of different reasons. These include utilitarian (commuting to work or school, travelling to public transport, or for shopping), social, health, and competition purposes. Recent Queensland surveys (Heesch, Garrard & Sahlqvist, 2010; Schramm, Haworth, Sticher & Rakotonirainy, 2010) suggest that much more recreational cycling than riding to work occurs. Unpublished CARRS-Q data suggest that health and fitness is the primary reason people ride a bicycle, followed by commuting, and social/ recreational purposes. Few people cycle for competition, or utilitarian purposes other than commuting (shopping, travel to public transport or travel to school).

There are a number of different methods used to measure cycling participation. Bicycles can be counted using observations or automatic counters. Other measures include bicycle ownership or bicycle sales, and self-reported measures of number of trips per week, kilometres travelled or time spent cycling. Bicycle ownership or sales values are an indirect measure, and may not accurately reflect actual use. Other measures are better: .the number of trips taken is a robust measure, with less error, and research suggests that recall of time spent cycling is more accurate when compared with self-reported kilometres travelled (unless riders use an accurate bicycle computer).

3.7.1.1 Australia

Limited work has been conducted in Australia specifically to evaluate the effect of helmet legislation on cycling participation. A large study in Melbourne collected data from a number of sites prior and subsequent to the introduction of the helmet wearing laws. This research demonstrated a doubling in the use of bicycles by adults in metropolitan Melbourne. However, there was a decrease in the use of bicycles by children. A decrease in cycling exposure of 10% was observed in children (5-11 years) and an even larger decrease of 44% for teenagers (12-17) (Finch et al, 1993).

Cycling participation rates have been examined by state and local governments in recent years. Census data from South East Queensland suggests that the number of journeys to work by bicycle fell after the introduction of helmet legislation (over 10,000 trips per day to just under 9,000 trips today), although the most recent available data suggests the absolute numbers now exceeds pre-legislation trip numbers. Measured as a proportion of mode share, bicycle trips to work have fallen from 1.6% pre-legislation (which was higher than the previous figure) to 1.1% post- legislation. State-wide data shows the mode share of cycling slightly higher at 1.4% in 2006. However, this excludes the number of trips taken by for purposes other than commuting (recreation, social, health and fitness, training etc.).

The cycling section of the Sustainable Transport Survey 2010 (described in more detail later) reports the average number of times per year that respondents who owned bicycles reported cycling in the years 2001-10 (MCR, 2010). Of the WAVE Survey population in 2010, 35.2% (144) indicated that they cycle at least once per year. The average frequency was highest in 2002 (68.7 times) and lowest in 2008 (42.7 times). There appeared to be a general overall reduction in the frequency of riding among the surveyed bicycle owners in Queensland. However this is difficult to interpret without considering ownership rates and trip distances.

Research studies, bicycle counts, sales data and anecdotal evidence suggest that cycling is increasing in popularity. No regular information regarding bicycle travel, for commuting or other purposes, is collected in Queensland. However, bicycle sales figures collected by the bicycle retail industry indicate that bicycle sales have outpaced motor vehicle sales in Australia since 2000 (Cycling Promotion Fund, 2010). Despite the perception that only children cycle, figures indicate that 1.66 times more adult than children's bicycles are sold nation-wide. This figure ranges from 1.42 to 2.01 across states (Cycling Promotion Fund, 2006). The most frequently purchased bicycle type is "Mountain Bikes" (approximately 70%), followed by "City/Hybrid Bikes" (approximately 20%), and lastly "Road Bikes" (just over 10%).

Commuter cycling counts in Melbourne have shown an increase since 2006, with a 43% increase in counts between 2007 and 2008 (Melbourne City Council, 2008). Data from Western Australia, collected by automatic counters, have shown an increase in the total number of cyclists travelling on bicycle paths in Perth. These counts show an increase in the total number of trips between 2008 and 2010 (Department of Transport, 2010). Bicycle increase in the Sydney metropolitan area increased by 23% on weekdays and 58% on weekend days from 2001 to 2005 (RTA, 2008 cited in PricewaterhouseCoopers, 2009).

3.7.1.2 International

There have been several international studies that have examined the effect of introduction of mandatory helmet legislation for children on cycling participation rates, which have reported differing results.

Legislation compelling children to wear bicycle helmets was introduced in Ontario during 1995. An observational study counted the number of child cyclists per hour at 111 sites in 1993-1997 and in 1999 in a defined urban community in Ontario (Macpherson, Parkin & To, 2001). The number of child cyclists per hour differed significantly from year to year, but not in a way that could be attributed to the legislation. The year after the legislation came into effect, average cycling levels were higher than the year before the legislation (6.84 versus 4.33 cyclists per hour).

Research from the United States has found that there has been a 5% reduction in cycling by children following the introduction of compulsory helmet wearing legislation for children. While it has been hypothesised that a reduction in children cycling would reduce the overall participation in physical activity, this was not the case (Carpenter & Stehr, 2008). There was no evidence that there was a reduction in participation in a variety of physical activities (strengthening exercises, participation in sports teams, exercise to lose or maintain current weight, or vigorous exercise of at least 20 minutes in duration in the previous week) (Carpenter & Stehr, 2010).

It is important to recognise the possible role of other factors in changes in cycling participation. Research from locations where helmet wearing is not compulsory has identified many other factors as barriers to cycling. These factors include environmental factors (weather), geographical factors (distance required to travel), safety (perceived levels of safety), as well as psychological factors (Eriksson, 2009).

3.7.2 Attitudinal surveys

This section examines any reported disincentives to cycling from compulsory helmet wearing by analysing attitudinal surveys (WAVE) and other available attitudinal data.

3.7.2.1 Queensland WAVE attitudinal surveys

TMR has conducted an annual survey of Queensland motorists since 2001 that has covered a wide range of road safety and transport topics (the WAVE surveys). Until 2007 the survey was administered by Computer Assisted Telephone Interviewing (CATI), but from 2008 the survey has been administered via an online panel method. In 2010, an additional survey that focused on sustainable transport issues was conducted that included some of the questions from earlier surveys.

The survey includes only persons aged 18 years and above. This means that the results are relevant only to adults, whose cycling and helmet use may differ from that of children and adolescents. Research indicates that teenagers (aged 11-19) are the age group least likely to wear helmets (Berg & Westerling, 2001; Lin et al., 1998; Thomas et al., 1994), and children have the highest exposure to bicycle riding with also a lower helmet use than the adult population, which adds additional bias in the representativeness of this finding translated to the entire cycling population (Finnoff, Laskowski, Altman & Diehl, 2001).

The question about barriers to riding a bicycle was asked only of those respondents who reported owning a bicycle but never riding it (n=20 in 2010 and similar numbers in earlier years). This small sample size introduces a large error into this measurement, therefore it is unlikely that this finding is representative of the population. In 2003 to 2007, the question "why don't you ride your bicycle?" was asked without providing prompts, while in 2008 to 2010 prompts were provided. The 2010 report (MCR, 2010) does not state whether the order of the prompts was randomised.

The TMR 2010 WAVE survey surveyed participated aged over 18 years, who hold a current drivers licence and drive regularly (more than 1 person hour week). 409 participants responded to the questionnaire on cycling issues/ pedestrian issues/ end of trip facilities and public transport. However, only 20 participants owned a bicycle but did not ride it, and it was only this group that was asked to responded to the part of the survey dealing with barriers to cycling.

Interpreting the WAVE data is difficult. In the July 2002 WAVE survey, 38 bicycle owners who do not ride were asked about barriers to riding, with unprompted responses. The main reason given was that "helmets are compulsory" (29%), and 19 other reasons were also nominated. However the picture presented by later WAVE surveys is both quite different to this, and quite variable.

There are limitations on the data reported here, as the main source of historical data is the report on the 2010 WAVE survey. It presents historical data going back to 2003 in a figure, but only to 2004 in a table. There are several notable changes in the patterns of response in this series. While the figure presents only selected data, none of which relates to the nomination of compulsory helmet wearing as a barrier, in the table it appears not to have been mentioned in any of the WAVE surveys from 2004 to 2008. Over this period the most common barriers mentioned were "too old/grew out of it" in 2004 (13%), "unsafe environment/roads not safe" in 2005 (32%) and 2007 (equal top, 29%), "no time/too busy" in 2006 (30%) and 2007 (equal top, 29%), and was shared in 2008 by "need to carry things/not large enough capacity" and "have arthritis in joints", both at 27%.

The latter results, in 2008, were the first time that prompts were used rather than unprompted responses, but helmet legislation was not one of the prompts. In 2009 and 2010 "helmets are compulsory" was included in the prompts, and was nominated by 19% of respondents in each year. In 2009 the most common response was "got vehicle/car" (40%), with "helmets are compulsory" being sixth, while in 2010 the most common response was "got drivers licence" (51%) with "helmets are compulsory" being ranked tenth, along with two other reasons. It is not stated whether the order of the prompts was randomised.

The most likely explanation for this highly variable and inconsistent picture is the small numbers involved, combined with the use of weights. Only people who owned a bicycle but did not ride were asked about barriers, a group of only 38 respondents in 2002. The number in 2003 is not available, but numbers of these people from 2004 to 2010 were (in ascending order of year) 33, 37, 40, 29, 10, 12 and 20. The weighting system accounts for the derivation of a figure of 19% of people nominating "helmets are compulsory" in 2009 and 2010, which in practice amounted to 2 and 4 respondents respectively before weighting. For these numbers weighting is simply not meaningful, and the numbers themselves are too small to justify much attention.

It is worth noting that, even if there had been a sufficiently large sample size, the structure of the question means that it is very difficult to interpret the impact of removing any of the listed barriers. Respondents were able to select any option from the list, i.e. they could select all of them as barriers, if they chose to. The implication is that the removal of one barrier (such as compulsory helmet wearing) may have a negligible impact on uptake of cycling if all the other barriers remain. In the future it would be advisable to restrict the number of choices respondents could make, e.g. by asking them to select the "most important" or "three most important" barriers. It would also be preferable to set a target sample size for the cycling subgroups of interest.

Another issue relates to the focus on those people who have a bicycle but do not use it. As noted above, the scanty results from this research suggest that the legalisation of helmet wearing is likely to have little impact on cycling in this group. At a broader level, it is worth asking whether this group of bicycle owners who do not ride is the appropriate target, i.e. whether it would be better to determine whether compulsory helmet use is a barrier to the greater uptake of cycling at a broader level. For example, when the 153 bicycle owners in the 2002 WAVE survey were asked what would encourage them to cycle more only 7% nominated repeal of bicycle helmet legislation (behind "if had more time" 21% and "better cycling facilities" 9%). It appears from calculation that this 7% constitutes 11 people, which is the same number that nominated "helmets are compulsory" as a barrier to cycling when only those 38 bicycle owners who had not ridden were asked about barriers to cycling.

3.7.2.2 Other Australian attitudinal surveys

Qualitative and quantitative research conducted mainly in Australia provides both direct and indirect information relevant to compulsory helmet wearing.

A study conducted on the Gold Coast with adolescent bicycle riders revealed that the sample had positive attitudes towards helmet use, experienced a high social pressure to use helmets, and moderate levels of moral obligation and control to wear helmets (O'Callaghan & Nausbaum, 2006). Interestingly, helmet users believed helmets provided them with more protection from injury than non-users (O'Callaghan & Nausbaum, 2006). This finding suggests that the legislation provides a mechanism for encouraging individuals who underestimate the protection offered by helmet use to wear their helmet, despite them not seeing the need.

Qualitative and quantitative research into barriers to cycling has recently been undertaken in New South Wales, using the Theory of Planned Behaviour as a means of understanding the factors that contribute to, or detract from, cycling (AMR Interactive Contacts, 2009). The qualitative research (which was comprised of ten focus groups covering different categories of cyclists and locations) found that women and young people expressed concerns about how helmets affected their appearance (or rather, how well-presented they were) or the impression they gave. The qualitative data was used to develop a telephone survey of 301 people stratified by gender, location and age. Questions were asked about reasons for not cycling (free responses), separately for particular types of cycling and particular subgroups within the sample. "Infrequent/non-cyclists" (n = 235) were asked about their reasons for not cycling for recreation or exercise, giving 27 response categories classified into 7 groups. The largest group was "health/ability to ride issues" (36%), while the largest individual items were "time constraints/ lack of time" (19%), "medical reasons/unable to ride" (18%) and "safety reasons/roads too dangerous" (18%). No items mention helmets, with the only possibly relevant item being "clothing", which was nominated by only one respondent. People who lived "within 10km of work/train/ ferry" (n = 99) were asked about their reasons for not commuting by bicycle, also giving 27 response categories (not all the same as above) in 7 groups (not all the same as above). The largest group was "feasibility/convenience" (32%), while the largest individual item was "safety reasons/roads too dangerous" (23%; next highest was only 14%). Again helmets are not mentioned, though the "clothing issues" item accounts for 5% of responses.

Focus groups were conducted in Melbourne with women, to determine barriers to cycling (Garrard & Hakman, 2005). While a great deal of rich information was obtained, it appears that the only issue raised about helmets related to the problem of adjusting the straps correctly. A later summary of the overall project that this research was part of (Garrard, Crawford & Hakman, 2006) also reported the results of an online survey of 2403 men and women. Constraints on cycling were investigated, resulting in a list of 20 constraints. The authors note that "Having to wear a helmet was the least important constraint for both males and females" (p. 5).

A tracking survey of people over 18 years of age was conducted in Western Australia by TNS Social Research (2007) as part of a program aimed at increasing levels of cycling. There appears to have been no explicit mention of helmet wearing among the questions, apart from one item among 17 "attitudes affecting cycling behaviour", for which respondents were asked to rate how much something would affect their cycling behaviour on a 5 point scale ranging from "a lot" to "not a lot". Despite the title, the 17 items were a mixture of attitudes (e.g. "dislike wearing a helmet"), aims (e.g. "improving your fitness") and contextual issues (e.g. "having a health problem") and are presented in the one figure without any consideration of the need for reverse scaling (e.g. when "dislike helmet wearing" is said to affect cycling "a lot" it is a barrier to cycling, but when "saving money on petrol" is rated as affecting cycling "a lot" it is a facilitator of cycling). Both of these issues make the data hard to interpret, however since the 22% of cyclists who say that "dislike helmet wearing" affects their cycling "a lot" is only greater than the 19% of people who say that "having health problems" affects their cycling "a lot", while all responses at the other end of the scale (i.e. "not a lot") are selected by at least 32% of respondents, it is reasonable to conclude that helmet wearing is not a significant barrier.

A report by Rissel, Merom, Bauman, Garrard, Wen and New (2010) on willingness to cycle in a community survey in Southwest Sydney found that many of the respondents wanted to ride more, however there were only four factors which were found to be associated with riding in the past year, wanting to ride more, or having used local cycle paths (these were grouped): "has access to a bicycle" (odds ratio [OR] 28.40); "male" (OR 3.33); "young" (OR 1.39); and "live close to destinations" (OR 1.62) . It appears that the issue of helmet wearing was not raised in the survey (although this is unclear), and believing that it is "safe to use bike paths" and it is "important that cycling be easy" were not associated with riding in the past year, wanting to ride more, or having used local cycle paths. The main implication of these results is that access to a bicycle is the primary barrier to cycling. Taken together with the research into the average number of cycling trips undertaken, it suggests that a substantial number of cycle trips (in particular, recreational trips) are to some extent "opportunistic", i.e. on a given occasion a person might decide to go for a ride, provided a bicycle is available, but cycling as a recreational activity in its own right is not planned for. Under these circumstances, it is likely that a helmet would be worn if it is available, so that selling bicycles and helmets together is likely to create the circumstances in which such opportunistic recreational cycling will involve helmet use.

3.7.2.3 International research

International research on attitudes to compulsory helmet wearing is sparse, perhaps because few jurisdictions have universal bicycle helmet laws. One interesting exception is a 1994 study of the psychosocial factors associated with helmet use among primary and secondary age children (Gielen et al, 1994). The researchers compared three counties in Maryland, USA, one of which had a helmet law, one an education program, and the third neither. It was found that the main barriers to helmet wearing were social concerns, regardless of whether there was a helmet law or not.

3.8 Conclusions regarding bicycle helmet legislation

A review of the most scientifically rigorous research concluded that bicycle helmets that meet national standards protect against head, brain, and facial injuries. Helmet wearing was associated with a 69% reduction in the likelihood of head or brain injury and a 74% reduction in the likelihood of severe brain injury. The benefit was the same whether a motor vehicle was involved in the crash or not. Helmet wearing reduced the likelihood of injury to the upper and mid-face by 65%.

In Australia, bicycle helmet wearing laws are universal in approach, applying to bicycle riders and pillions of all ages who are riding on roads and road-related areas (except in Northern Territory where it applies on roads only). Road-related areas include most riding locations. Bicycle helmet wearing laws have been introduced in many other jurisdictions in North America and Europe but most commonly apply only to children (or applies to certain riding areas only in a small number of countries).

The introduction of bicycle helmet wearing legislation has led to increases in wearing rates in jurisdictions where the legislation is universal (with lower rates but still increased for teenagers) and where it applies to children only.

Australian and international research has demonstrated that introduction of bicycle helmet legislation was followed by a reduction in the number and severity of head injuries to cyclists. New Zealand research shows that the legislation has good cost-effectiveness. In support of this conclusion, changes to US motorcycle helmet laws have shown that head injury (and overall fatality and injury) rates have increased when universal laws were repealed and returned to earlier levels when laws were reinstated.

The ability to assess the effects of bicycle helmet laws on cycling participation rates is constrained by the lack of long-term participation data that covers all types of riding. It is also difficult to predict what current cycling participation levels might have been under different scenarios.

Limited work has been conducted in Australia specifically to evaluate the effect of helmet legislation on cycling participation. In Melbourne adult cyclist numbers doubled after the helmet legislation was introduced but there were fewer child cyclists, particularly teenagers. Data from South East Queensland suggests that the number of journeys to work by bicycle fell after the introduction of helmet legislation but now exceeds pre-legislation trip numbers. However, this excludes the number of trips taken by for purposes other than commuting (recreation, social, health and fitness, training etc.).

Research studies, bicycle counts, sales data and anecdotal evidence suggest that cycling is increasing in popularity. There is evidence that the number of commuter cyclists has increased in Melbourne since 2006, and that the total number of cyclists travelling on bicycle paths in Perth increased between 2008 and 2010.

The WAVE surveys undertaken in Queensland provide little reliable information on the extent to which compulsory helmet wearing is a disincentive to cycling because of the very small number asked this question and the variations in how the question has been asked over time. Even among the small sample of respondents, compulsory helmet wearing was almost never provided as an unprompted response and it was the sixth or tenth most common response when prompted. Other Australian surveys have also reported that compulsory helmet wearing ranks very low among a long list of reasons for not riding a bicycle.

There is mixed evidence regarding the effect of mandatory helmet use for children on cycling participation in international studies. Research from locations where helmet wearing is not compulsory has identified many other factors as barriers to cycling including weather, distance, perceived levels of safety and other psychological factors.

4. ANALYSES OF CYCLIST CRASH AND HOSPITAL DATA

4.1 Outline of tasks

The tasks proposed to achieve this research deliverable are:

- Analyse Queensland crash data to determine the extent of injuries to cyclists with and without helmets;
- Summarise available Australian bicycle fatality data;
- Analyse hospitalisation data to determine the extent of injuries to cyclists with and without helmets; and,
- Review data for emergency department presentations by cyclists.

Where relevant, the data set used and its limitations are described before presenting results of analyses.

4.2 Analyse Queensland crash data to determine the extent of injuries to cyclists with and without helmets

4.2.1 Data set and its limitations

TMR has provided CARRS-Q with data on bicyclists in crashes in the years 1993-2008. Reliable earlier data were not available and so all of the crash data analyses relate to after the helmet law and the penalty were introduced. Some earlier published crash analyses in a report by King and Fraine (1994) are presented in section 3.6.1.

The current data set contains the following relevant variables:

- Year, date and time;
- Crash location variables;
- Rider gender and age;
- Crash characteristics (e.g. DCA, number of units involved);
- Crash severity;
- Helmet use; and,
- Contributing circumstances.

The data were analysed to measure:

- Trends in helmet use overall;
- Helmet use as a function of rider and crash characteristics;
- Trends in bicycle crash numbers and severities; and,
- Associations between helmet use and injury severity.

When examining bicycle crash patterns using police-reported data, it is important to acknowledge some of the limitations associated with the data. Research indicates that there is significant underreporting of bicycle crashes, and it is more extensive than for any other transport mode (Veisten et al 2007). International figures suggest between 11% (Stutts et al 1990) and 13% (Veisten et al 2007) of bicycle crashes are recorded in police statistics. The reporting rates are even lower in Australia, with analysis of Western Australia data suggesting that only 3.5% are reported (Hendrie & Ryan 1994). Actual reporting rates may be even lower, as these rates are calculated using hospital data. Research suggests many bicycle-related injuries are self-treated, and would not be included in hospital records either. There are also suggestions that police-reported data will not only underestimate the magnitude of the cyclist injury problem, but it is likely to be skewed to serious injury crashes and those that involve motor vehicles (Stutts et al 1990).

It is also important to note the differences in reporting between hospital and police data. While some variables are similar, injury data available in police-reported data differs from publicly available hospital injury data. Within the hospital data, only the primary reason for hospitalisation is reported. The police data records information on multiple injury sites.

There are also limitations placed on the data that is collected. To be included in the Queensland crash database, a crash must meet the following criteria:

- The crash occurred on a public road; and,
- A person was killed or injured; or,
- At least one vehicle was towed away; or,
- The value of property damage was:
  - o $2500 damage to property other than vehicles (after 1 December 1999).
  - o $2500 damage to vehicle and property (after 1 December 1991 and prior to 1 December 1999).

As a result, crashes that occur on private roads or on public paths that are not within the road reserve (eg. segregated bicycle paths through public parks) are excluded from the official records.

A number of other factors need to be considered when examining police crash data. New reporting systems were introduced during 2006, and between July 2006 and June 2007 several important data trends were observed. Of most relevance to this research:

- The number of all crashes reported during this period is below expected;
- A greater proportion of minor injury casualties and fewer hospitalisations were reported; and,
- An increase in unknown helmet use for bicyclist casualties.

Thus any changes in the patterns of crash severity, hospitalisation rates and other non-fatal data from 2006 onward may reflect changes in the reporting system, rather than changes in actual injury outcomes.

It is possible that for non-fatal crashes, riders who were not wearing helmets at the time would be less likely to report the crash to Police. If this occurred, it would contribute to the reported data tending to over-estimate helmet use. This issue is hard to assess from the available data.

4.2.2 Trends and characteristics of Police-reported bicycle crashes

A total number of 13,341 crashes involving bicycles were reported between 1 January 1993 and 31 December 2008. Total number of crashes rose from 817 to a peak of 926 in 1997. There were 820 crashes involving bicycles in 2008, which was more than in the previous two years (772 in 2006 and 750 in 2007), but almost the same as in 2005 (821). The decrease in reported crashes in 2006 and 2007 could reflect the data limitations mentioned above.

Due to the small number of fatalities reported, no clear trend is present. Medical treatment injuries have shown a downward trend during the data period, while there has been an increase in hospitalisation crashes. The upward trend in hospitalisation crashes may be a result of changes in hospital admission practices, or truly reflect a change in crash patterns (see Figure 1).

Five year averages show a steady decline in reported bicycle crashes. However, the average from 2003-2008 may be influenced by the data issues for 2006-2007 explained previously. Reviewing the five-year averages, the number of hospitalisations has increased, while there has been a decline in crashes resulting in medical treatment or minor injury (see Figure 2).

Almost all of the bicycle crashes reported to police involve motor vehicles, and therefore are a biased subset of bicycle crashes. The reporting of single bicycle and bicycle-motor vehicle crashes is outlined in Figure 3. These show a fairly steady rate of reports of single bicycle crashes (about 5% of the total), and some variability in the number of bicycle-motor vehicle crashes.

The majority of crashes (91.8%) reported involved bicycles and motor vehicles. Very few crashes involved multiple bicycles, bicycle(s) and pedestrian(s), or bicycle(s) and multiple road user types. A small proportion (5.1%) recorded were single vehicle bicycle crashes (see Table 5). There was a tendency for a larger proportion of crashes involving riders aged 0-4 to be single bicycle crashes (11.5%), and a smaller proportion to involve motor vehicles (88.5%). This was not true for children overall, for whom crashes were equally likely to involve a motor vehicle as crashes of adult riders.

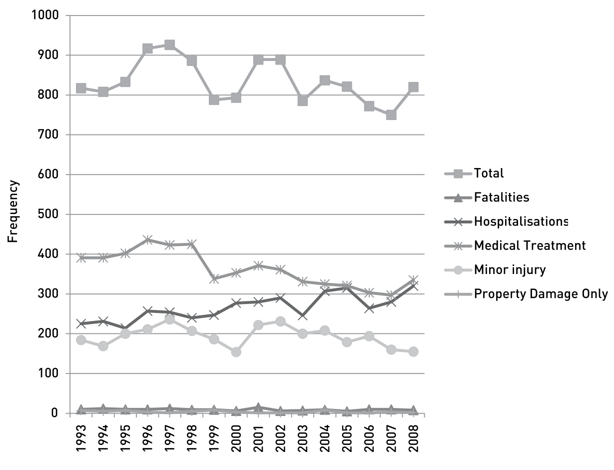

Figure 1. Trends in Queensland bicycle crashes 1993-2008.

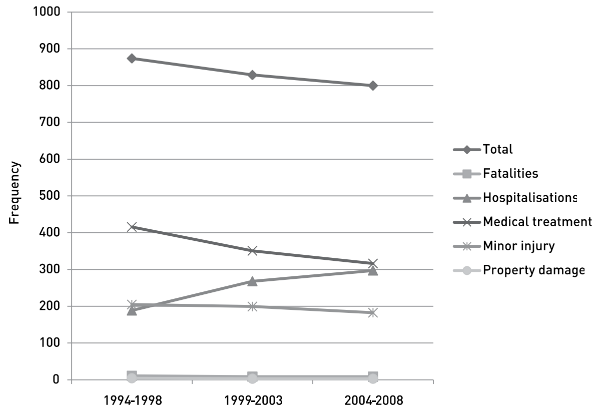

Figure 2. Five-year averages for Queensland bicycle crashes 1994-2008.

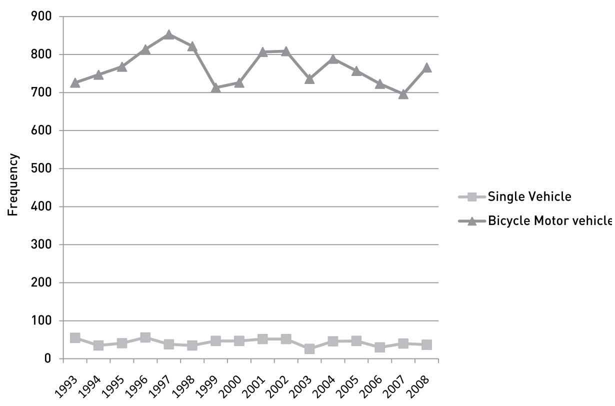

Figure 3. The number of single bicycle and bicycle-motor vehicle crashes reported 1993-2008.

Table 5. Units involved.

	Frequency	Percent
Single bicycle	684	5.1
Bicycle(s) and pedestrian(s)	185	1.4
Multiple (2+) bicycles	104	0.8
Bicycle and other	114	0.9
Bicycle(s) and motor vehicle(s)	12252	91.8
Bicycle and multiple other user types	12	0.1

Due to the nature of the data, it is not possible to determine the speed of the bicycle (or other road user) at the time of the incident. This is important, as the speed at impact can influence the severity of the injuries sustained. For the closest approximation, the speed limit of the road where the crash occurred has been examined. The largest proportion of bicycle crashes occur on roads signed with a speed limit of 60 km/h. This may reflect the riding patterns of Queensland cyclists. These figures show the greatest proportion of fatal bicycle crashes occur on roads where the speed limit is 60 km/h, followed by 100 km/h. However, it is important to note that bicycle fatalities and serious injuries have occurred when signed speeds are less than 40 km/h(see Table 6).

Table 6. Signed speed limit at bicycle crash locations, by injury severity.

Speed limit	Total	Fatality	Hospi-talised	Medically treated	Minor Injury
<40	60	1	14	19	26
40	377	7	106	147	117
50	1795	12	603	748	432
60	10307	73	3039	4619	2576
70	512	10	192	190	120
80	462	15	194	162	91
90	13	0	8	4	1
100	367	30	175	121	41
110	6	1	2	3	0

The data presented below are for the period 1993-2008 and so the relatively low representation of crashes in speed zones of 40 km/h and lower (3.3%) may reflect the infrequency of those speed zones in the early years. However, analysis of data from 2000-2008 showed a similar percentage of crashes in these low speed zones (3.8%), with no discernible increase across this time period. While the percentage of bicycle crashes in these lowest speed zones is quite low, it is still higher than for crashes of all types (mostly car crashes). The data for 2000-2008 show that only 0.2% of all crashes occurred in speed limits of 40 km/h or less. Whether the relatively greater representation in the lowest speed zones of bicycle crashes compared with all crashes reflects relatively more riding in these areas or the greater vulnerability of cyclists is not clear from this data.

The casualty data has also been examined. There were 57 crashes with no injuries reported. From the 13,284 crashes where an injury was reported, there were a total of 13,899 casualties. The greatest proportion of injuries reported was to bicyclists. Very few motor vehicle operators or passengers were injured in crashes involving bicycles (see Table 7). No fatalities were recorded for Drivers, Passengers or Motorcycle pillions (Table 8).

Injury severity data does not contain any missing data during the data period. The proportion of serious injury crashes for bicycle riders and pillions over time has been examined (see Figure 4). This shows the proportion of serious injuries (fatalities and hospitalisations) has increased over time. While the proportion of fatalities has remained fairly steady over time, there has been a trend of increasing cyclist hospitalisations since 1993.

The age distribution of cyclists involved in police reported crashes was explored. There has been a steady, and noticeable increase in the proportion of cyclists aged 25 years or older involved in police reported crashes (see Figure 5). The proportion of crashes involving cyclists aged 0-4 has remained steady. There has been a decrease in the proportion of cyclists aged 5-11, 12-17 and 18-24 in police reported crashes, with the most noticeable decline being the 12-17 age group.

Table 7. Number of casualties reported 1993-2008.

	Frequency	Percent
Bicycle rider	13358	96.1%
Bicycle pillion	90	0.6%
Pedestrian	181	1.3%
Motorcycle rider	84	0.6%
Motorcycle pillion	4	0.0%
Driver	146	1.1%
Passenger	36	0.3%

Table 8. Number of casualties, by injury severity, reported 1993-2008.

	Fatality	Hospi-talised	Medically treated	Minor Injury
Bicycle rider	144	4191	5805	3218
Bicycle pillion	2	26	38	24
Pedestrian	2	68	86	25
Motorcycle rider	1	23	29	34
Motorcycle pillion	0	2	0	2
Driver	0	21	37	88
Passenger	0	2	18	16

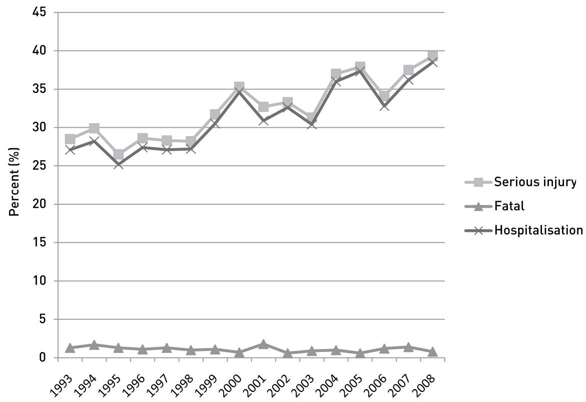

Figure 4. Trends in proportion of cyclist serious injury casualties 1993-2003.

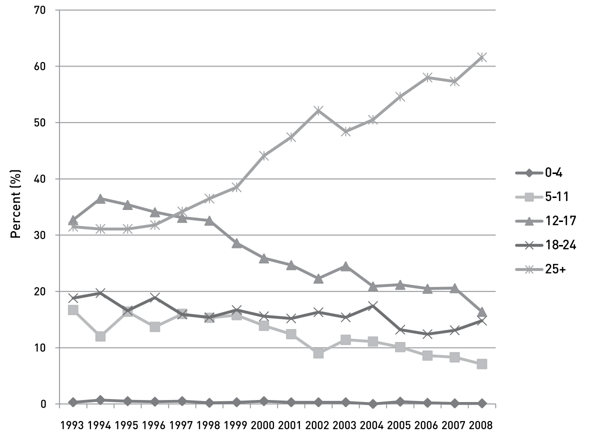

Figure 5. Percent of cyclists in crashes according to age.

4.2.3 Helmet use in Police-reported bicycle crashes

The use of helmets by cyclists, as well as the completeness of helmet use data, has also been examined. Results show a trend of decreasing proportion of cyclists injured who are not wearing a helmet. However, these findings may be influenced by the increase in helmet use being reported as "unknown" (see Table 9). Unknown helmet use increased over time across all severity levels (see Table 10). However, unknown helmet use is consistently higher in the minor injury categories. The variability in reporting for fatalities is likely due to the limited number occurring annually. Over time there has been a decrease in reported helmet use rates for minor injuries, while there has been a general trend to increasing helmet use rates for medical treatment and hospitalisation injuries. The helmet-use rates for fatal injuries continue to fluctuate over time (see Figure 6).

Table 9. Helmet use data.

Year	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
1993	135	16.3	639	77.4	52	6.3
1994	170	20.6	589	71.3	67	8.1
1995	164	19.1	611	61.2	83	9.7
1996	228	23.3	663	67.9	86	8.8
1997	193	20.3	662	69.5	98	10.3
1998	138	15.2	678	74.7	92	10.1
1999	138	17.3	587	73.5	74	9.3
2000	134	16.4	608	74.5	74	9.1
2001	117	13.0	683	75.7	102	11.3
2002	111	12.0	684	73.9	130	14.1
2003	110	13.6	583	72.1	116	14.3
2004	144	16.3	630	71.5	107	12.1
2005	96	11.3	647	76.3	105	12.4
2006	75	9.3	543	67.3	189	23.4
2007	70	8.8	578	72.3	151	18.9
2008	78	9.1	697	81.1	84	9.8

Table 10. Proportion of unknown helmet user reporting, by injury severity.

Year	Fatality	Hospita-lisation	Medical treatment	Minor injury
1993	9.1	8.0	4.8	7.3
1994	7.1	5.6	8.0	11.9
1995	36.4	6.9	9.0	12.6
1996	9.1	6.3	7.6	13.9
1997	16.7	7.8	9.3	13.7
1998	33.3	7.7	9.0	14.0
1999	0.0	4.5	9.4	15.1
2000	16.7	5.7	8.4	15.9
2001	0.0	7.2	6.6	25.0
2002	16.7	5.0	10.6	30.2
2003	14.3	8.9	8.1	31.0
2004	33.3	2.2	9.0	30.3
2005	0.0	6.0	7.1	30.9
2006	10.0	18.5	17.3	38.6
2007	18.2	10.7	18.2	33.0
2008	0.0	5.7	9.2	18.9

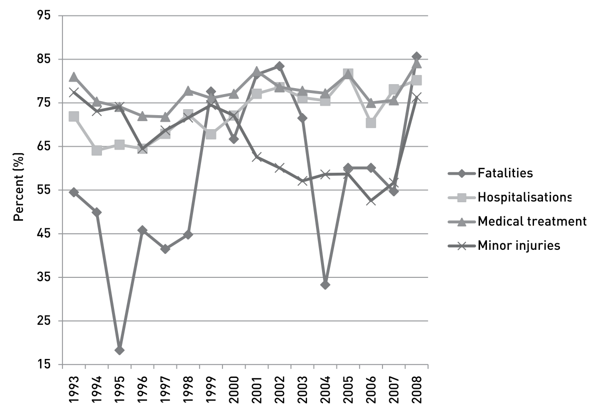

Figure 6. Cyclist helmet wearing rates by injury severity.

The casualty data will be examined in further detail. The body region(s) injured by road user type for all injury severities are reported in Table 11. Injury patterns differ across road user types. Bicycle riders are most likely to injure their lower limbs and shoulder/upper limbs. Head injuries account for less than 20% of injuries, with facial injuries slightly more common injuries to the skull or brain. Bicycle pillions are much more likely to suffer a head injury, with the proportion of head and facial injuries similar. Motorcycle riders are more likely to suffer upper limb injuries, while motorcycle pillions are more likely to suffer head injuries. Motor vehicle drivers are more likely to suffer injuries to their neck and abdomen, while passengers are more likely to suffer face, abdomen or upper limb injuries. Pedestrians experience a large proportion of injuries to their limbs and head.

Table 11. Body region injured by road user type, all injury severities.

	Bicycle rider		Bicycle pillion		Driver		Passenger		Motorcycle rider		Motorcycle pillion		Pedestrian	
Body region	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Head	1144	8.6	13	14.4	6	4.1	2	5.6	5	6.0	2	50.0	34	18.8
Face	1326	9.9	14	15.6	10	6.8	8	22.2	3	3.6	0	0.0	37	20.4
Head and/ or Face	2371	17.7	27	30.0	15	10.3	10	27.8	8	9.5	2	50.0	68	37.6
Neck	1194	8.9	14	15.6	27	18.5	6	16.7	8	9.5	0	0.0	14	7.7
Thorax	1461	10.9	13	14.4	11	7.5	5	13.9	9	10.7	0	0.0	16	8.8
Abdomen/ lower back/ pelvis	1811	13.6	15	16.7	20	13.7	8	22.2	10	11.9	0	0.0	15	8.3
Shoulder and upper limb	3442	25.8	10	11.1	14	9.6	42	23.2	34	40.5	0	0.0	42	23.2
Hip and thigh	2513	18.8	16	17.8	6	4.1	3	8.8	11	13.1	1	25.0	29	16.0
Lower limb	3883	29.1	20	22.2	13	8.9	4	11.1	24	28.6	1	25.0	45	24.9
Other injuries not specified	1526	11.4	12	13.3	3	2.1	2	5.6	10	11.9	1	25	10	5.5

Table 12. Body region injured by road user type for hospitalisation severity injuries.

	Bicycle rider		Bicycle pillion		Driver		Passenger		Motorcycle rider		Motorcycle pillion		Pedestrian	
Body region	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Head	752	17.6	10	22.2	1	3.6	0	0.0	5	12.5	3	100.0	25	29.1
Face	539	12.6	11	24.4	4	14.3	0	0.0	4	10.0	0	0.0	24	27.9
Head and/ or Face	1219	28.5	21	46.7	6	17.9	0	0.0	9	22.5	3	100.0	46	53.5
Neck	320	7.5	6	13.3	9	32.1	1	33.3	1	2.5	0	0.0	7	8.1
Thorax	610	14.3	8	17.8	7	25.0	1	33.3	2	5.0	0	0.0	10	11.6
Abdomen/ lower back/ pelvis	629	14.7	8	17.8	4	14.3	1	33.3	1	2.5	0	0.0	12	14.0
Shoulder and upper limb	1106	25.9	2	4.4	1	3.6	2	66.7	18	45.0	0	0.0	15	17.4
Hip and thigh	669	16.4	6	13.3	0	0.0	0	0.0	1	2.5	0	0.0	14	16.3
Lower limb	1165	27.3	11	24.4	1	3.6	0	0.0	15	37.5	0	0.0	18	20.9
Other injuries not specified	746	17.5	7	15.6	2	7.1	0	0.0	5	12.5	0	0.0	8	9.3

Table 12 presents the body region(s) injured by road user type for hospitalisation injuries only. It is important to note the low count of motor vehicle passenger and motorcycle pillion passenger hospitalisations. Bicycle riders are most likely to be hospitalised suffering from head injuries or injuries to the limbs, while pillions experience more head and lower limb injuries. Motorcycle pillions were only admitted for head injuries, while motorcycle riders were admitted for injuries to limbs. Injuries to the neck and thorax (chest) resulted in the most hospitalisations for motor vehicle drivers, while pedestrians suffered a greater proportion of upper limb injuries. Pedestrians were most likely hospitalised as a result of head, face and lower limb injuries.

The injuries to cyclists (riders and pillion) have been examined in further detail. There was a particular focus on the use of bicycle helmets. In Table 13, the distribution of injury is presented as a function of helmet use. The proportion of fatalities and hospitalisations is higher for cyclists not wearing a helmet.

The odds ratio for the effects of helmet wearing on fatality versus hospitalisation using the data in Table 13 is 0.49 – this means that wearing a helmet halves the odds of a fatality compared to a hospitalisation. However, there is a much larger percentage of hospitalised riders than fatally injured riders for whom helmet status is unknown, which could be influencing the odds ratio. If it is assumed that all riders for whom helmet status was unknown did not wear helmets the odds ratio drops to 0.46. If all fatally injured or hospitalised riders whose helmet status was unknown had worn helmets, the odds ratio increases to 0.55. Thus, the effect of the unknown data on the odds ratio is not large.

The body region injured was also examined, and helmet use was examined (see Table 14). The proportion of head injuries and facial injuries was lower for those riders who were wearing a bicycle helmet. Injuries to other body regions did not differ noticeably between helmet wearing riders and non-helmeted riders, except for shoulder and upper limb injuries.

The odds ratio for the effects of helmet wearing on head injury versus no head injury using the data in Table 14 is 0.40 – this means that wearing a helmet reduces the odds of a head injury by 60% compared to not wearing a helmet. However, whether a head injury resulted was unknown for 24% of riders wearing helmets and 20% of riders not wearing helmets. In addition, helmet wearing status was unknown for 7% of riders with head injury and 10% of riders without head injury. If it is assumed that all riders for whom helmet status was unknown did not wear helmets the odds ratio increases to 0.55. If riders whose helmet status was unknown had worn helmets, the odds ratio decreases to 0.39.

Table 13. Bicycle injury severity by helmet use.

	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
Fatality	44	2.2	82	0.8	20	1.3
Hospitalised	808	39.7	3102	31.5	307	19.7
Medical treatment	775	38.0	4528	46.0	540	34.7
Minor injury	410	20.1	2142	21.8	690	44.3

Table 14. Body region injured for all cyclists, by helmet use.

	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
Head Injury	347	17.0%	727	7.4%	83	5.3%
Facial Injury	325	16.0%	936	9.5%	79	5.1%
Head and/or Facial Injury	647	31.8%	1593	16.2%	158	10.2%
Neck	188	9.2%	907	9.2%	113	7.3%
Thorax	213	10.4%	1139	11.6%	122	7.8%
Abdomen/Lower Trunk	258	12.7%	1421	14.4%	147	9.4%
Shoulder/Upper Limb	375	18.4%	2793	28.3%	284	18.2%
Hip/Upper Thigh	367	18.1%	1858	18.8%	304	19.5%
Lower Limb	603	29.6%	2884	29.3%	416	26.7%
Unknown	399	19.6%	2389	24.2%	399	37.2%
Serious Head Injury (Concussion or worse)	190	9.3%	433	4.4%	58	3.7%

Odds ratios were also calculated for the occurrence of serious head injury using the data from Table 14. If unknown values are excluded, the odds ratio for serious injury for helmet wearing is 0.47, a 53% reduction in the odds of serious head injury. The odds ratio increases to 0.59 if it is assumed that all riders for whom helmet status was unknown did not wear helmets. If all riders whose helmet status was unknown wore helmets, the odd ratio remained at 0.47.

The odds ratio for head and/or facial injury using the data in Table 14 is 0.42 if missing values are excluded, 0.40 if it is assumed that riders with missing helmet status data were wearing helmets and 0.61 if it is assumed that riders with missing helmet status were not wearing helmets.

While bicycle riders make up the large percentage of injured cyclists, it is important to note that there was a small percentage (0.7%) of pillion riders. And that the helmet wearing rates for bicycle pillions was much lower than for bicycle riders (see Table 15).

Table 15. Helmet wearing rates, by bicycle rider type.

	Not worn	Worn	Unknown
Bicycle rider	1975 (14.8%)	9832 (73.6%)	1550 (11.6%)
Bicycle pillion	62 (68.9%)	22 (24.4%)	6 (6.7%)

4.2.4 Analyses of Police-reported bicycle crashes by age of cyclist

The following analyses examine crash and injury data variables by the cyclists' age. There are 151 cases (1.1%) of cases where cyclist age is unknown.

There are no apparent trends in crash severity patterns over time for cyclists in the 0-4 years' age group (see Figure 7 to 11). This is due to the small number of cases in the data set. Trends over time indicate a higher proportion of fatalities for cyclists aged 25 year or older. All age groups show an increase in the proportion of hospitalisations, and a decrease in minor injury and medical treatment cases, over time. The overall proportion of medical treatment cases appears slightly lower for school aged children (5-17 years), when compared with cyclists aged 18 years or older.

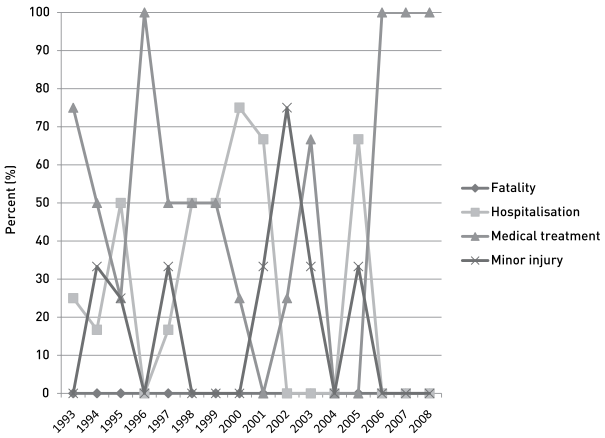

Figure 7. Crash severity patterns over time, cyclists aged 0-4.

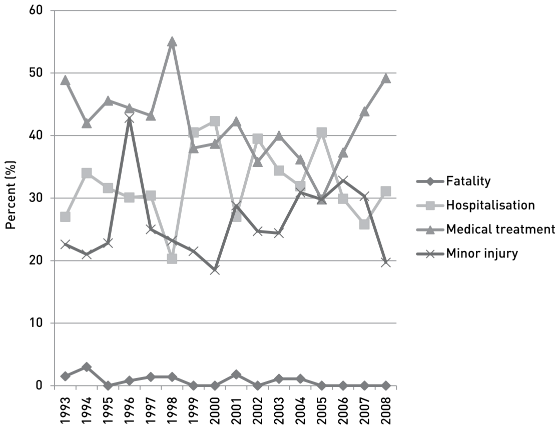

Figure 8. Crash severity patterns over time, cyclists aged 5-11.

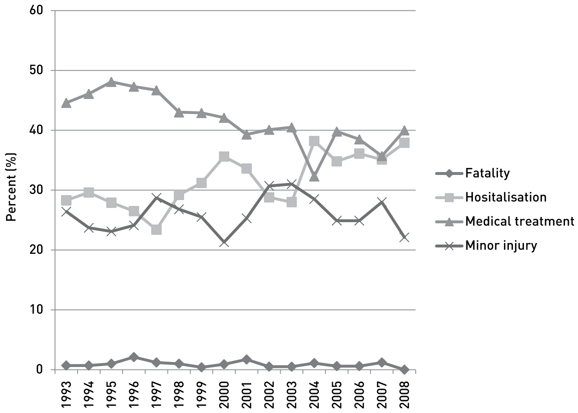

Figure 9. Crash severity patterns over time, cyclists aged 12-17.

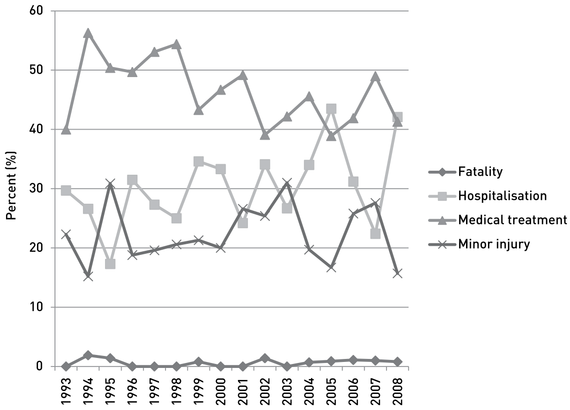

Figure 10. Crash severity patterns over time, cyclists aged 18-24.

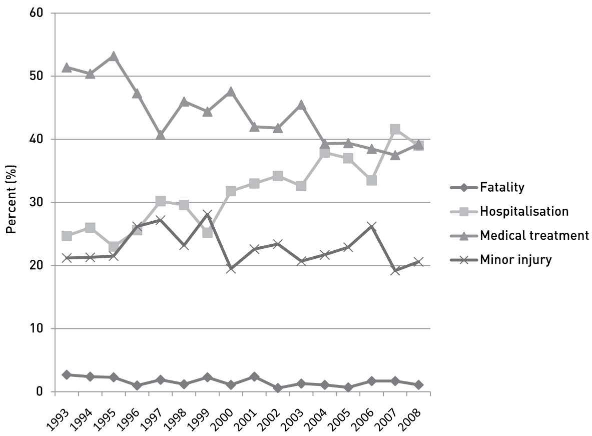

Figure 11. Crash severity patterns over time, cyclists aged 25 and older.

Trends in helmet use by cyclist casualties across the age groups were examined. These figures indicate that recorded helmet use rates are fairly consistent among cyclists aged 25 years or older, with rates approximately 80% (see Figure 12). Helmet use trends are the lower for younger riders, although the helmet wearing rates appear similar for primary and secondary school aged children (5-11 group and 12-17 group).

The proportions of reported bicycle crashes involving a single bicycle, a bicycle and a pedestrian, multiple bicycles, and bicycles and motor vehicles by rider age group are presented in Figure 13. There are very few crashes involving cyclists aged 0-4 years, with crashes being only single bicycle or bicycle-motor vehicle. The vast majority of bicycle crashes reported to police involve a motor vehicle, with observed rates being slightly higher for school aged children (5-17). Single bicycle crashes accounted for relatively more reported crashes for cyclists aged between 0-4 years than for other riders.

The signed speed limit at bicycle crash locations was examined by age group (see Table 16). This data demonstrates that the majority of crashes occur on roadways where the posted speed limit is 60 km/h, regardless of the cyclists' age. Younger riders (aged 11 years or younger) are less likely to be involved in crashes on roadways with higher speed limits (≥70 km/h), or with very low speed limits (<40 km/h).

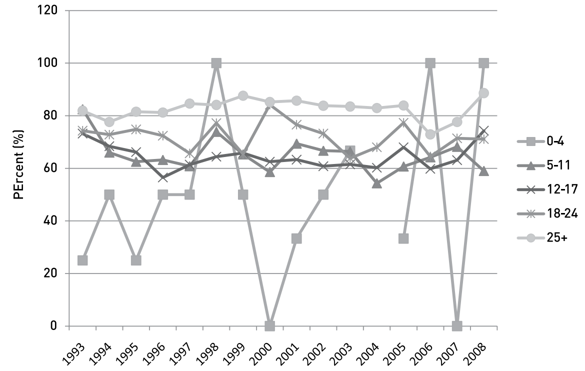

Figure 12. Proportion of helmet use by bicycle casualty age over time.

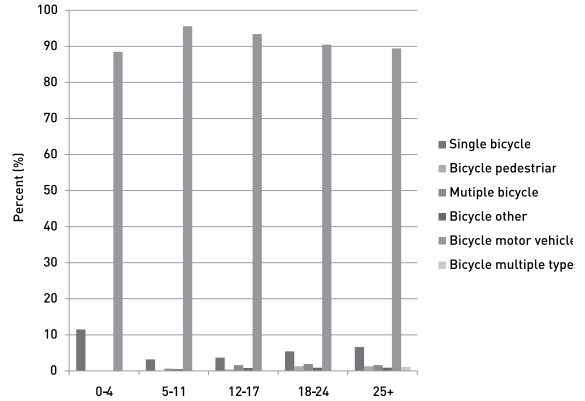

Figure 13. Proportion of vehicle involvement in bicycle crashes, by age group.

Table 16. Signed speed zone by age group.

	0-4		5-11		12-17		18-24		25+	
Speed limit	Count	%	Count	%	Count	%	Count	%	Count	%
<40	0	0.0	2	0.1	20	0.5	12	0.6	24	0.4
40	0	0.0	42	2.5	119	3.2	45	2.1	156	2.6
50	12	23.1	292	17.4	399	10.6	238	11.3	818	13.6
60	39	75.0	1236	73.7	2911	77.1	1620	77.1	4307	71.4
70	1	1.9	44	2.6	126	3.3	81	3.9	248	4.1
80	0	0.0	31	1.8	102	2.7	61	2.9	276	4.6
90	0	0.0	0	0.0	3	0.1	3	0.1	7	0.1
100	0	0.0	30	1.8	95	2.5	41	2.0	193	3.2
110	0	0.0	0	0.0	0	0.0	0	0.0	7	0.1

The injury patterns as a function of helmet use were examined for the five age groups (see Table 17 to 21). For all age groups, head and facial injuries were greater for those not wearing helmets. Upper and lower limb injuries were common across age groups, regardless of helmet use. It is difficult to draw conclusions regarding the injury patterns of young children (aged 0-4), due to the limited cases available. Both helmeted and non helmeted cyclists aged 0-4 demonstrated a high proportion of head injuries, while cyclists without helmets also had a higher proportion of lower limb injuries in this age group.

The injury patterns of cyclists aged were similar for riders aged 5 years or older who were wearing helmets, with the three most common injured body regions being the lower trunk or limbs. The proportion of face and head injuries differed within age groups, with head and face injuries less common for riders aged 18 years and above. Injury patterns for cyclists not wearing helmets differed in the four age groups. Riders in these age categories not wearing helmets were most likely to injure the limb or face, although this was more noticeable in the cyclists aged 5-11 years.

Table 17. Injury pattern by helmet use for cyclists aged 0-4.

	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
Head Injury	4	23.5	6	26.1	2	16.7
Facial Injury	1	5.9	4	17.4	0	0.0
Head and/ or Facial Injury	5	29.4	9	39.1	2	16.7
Neck	2	11.8	5	21.7	2	16.7
Thorax	1	5.9	4	17.4	0	0.0
Abdomen/ Lower Trunk	3	17.6	4	17.4	2	16.7
Shoulder/ Upper Limb	3	17.6	4	17.4	1	8.3
Hip/Upper Thigh	5	29.4	2	8.7	2	16.7
Lower Limb	5	29.4	4	17.4	3	25.0
Unknown	4	23.5	4	17.4	6	50.0

Table 18. Injury pattern by helmet use for cyclists aged 5-11.

	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
Head Injury	85	20.3	105	9.6	10	6.2
Facial Injury	78	18.6	128	11.6	14	8.8
Head and/ or Facial Injury	157	37.5	231	21.0	24	15.0
Neck	51	12.2	84	7.6	10	6.2
Thorax	41	9.8	104	9.5	7	4.4
Abdomen/ Lower Trunk	43	10.3	120	10.9	8	5.0
Shoulder/ Upper Limb	62	14.8	210	19.1	16	10.0
Hip/Upper Thigh	72	17.2	214	19.5	40	25.0
Lower Limb	116	27.7	366	33.3	54	33.8
Unknown	74	17.7	258	23.5	56	35.0

Table 19. Injury pattern by helmet use for cyclists aged 12-17.

	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
Head Injury	150	15.4	170	7.0	27	7.2
Facial Injury	125	12.8	243	10.0	19	5.0
Head and/ or Facial Injury	263	27.0	395	16.3	44	11.7
Neck	78	8.0	199	8.2	26	6.9
Thorax	111	11.4	213	8.8	29	7.7
Abdomen/ Lower Trunk	127	13.0	283	11.7	34	9.0
Shoulder/ Upper Limb	177	18.2	541	22.3	69	18.3
Hip/Upper Thigh	185	19.0	512	21.1	87	23.1
Lower Limb	305	31.3	837	34.6	131	34.7
Unknown	218	22.4	589	24.3	111	29.4

Table 20. Injury pattern by helmet use for cyclists aged 18-24.

	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
Head Injury	56	16.2	116	7.7	13	5.4
Facial Injury	62	18.0	141	9.3	12	5.0
Head and/ or Facial Injury	116	33.6	251	16.6	24	10.0
Neck	29	8.4	156	10.3	14	5.8
Thorax	37	10.7	166	10.9	19	6.7
Abdomen/ Lower Trunk	42	12.2	240	15.8	22	9.2
Shoulder/ Upper Limb	73	21.2	431	28.4	48	20.0
Hip/Upper Thigh	65	18.8	265	17.5	40	16.7
Lower Limb	91	28.1	414	27.3	63	26.2
Unknown	65	18.8	366	23.4	96	40.0

Table 21. Injury pattern by helmet use for cyclists aged 25 years and older.

	Not Worn		Worn		Unknown	
	Count	%	Count	%	Count	%
Head Injury	58	17.8	348	7.0	34	4.7
Facial Injury	66	20.2	442	8.9	26	3.6
Head and/ or Facial Injury	119	36.5	744	14.9	59	8.2
Neck	33	10.1	485	9.7	57	7.9
Thorax	33	10.1	681	13.6	69	9.6
Abdomen/ Lower Trunk	53	16.3	810	16.2	80	11.2
Shoulder/ Upper Limb	64	19.6	1665	33.3	143	19.9
Hip/Upper Thigh	46	14.1	908	18.1	127	17.7
Lower Limb	87	26.7	1319	26.4	155	21.6
Unknown	52	16.0	1218	24.4	284	39.6

4.3 Summarise available Australian bicycle fatality data

4.3.1 Data set and its limitations

This section will presents Australian bicycle fatality data presented in published reports and on relevant websites. Primary references will include the Australian Transport Safety Bureau reports, "Cycle safety: A national perspective." (2004), "Deaths of cyclists due to road crashes" (2006) and "Road Deaths Australia 2008: A statistical summary" (2009). Some of the detailed data (such as helmet wearing) is dated and any fatalities occurring in off-road riding are not included.

4.3.2 Numbers and characteristics of bicycle fatalities

In 2009, there were 31 cyclists (riders and pillions) killed across Australia, with 8 of these occurring in Queensland.

For the period 1991-2009, most cyclist fatalities have been males (85.6% in Australia, 85.4% in Queensland) and about a quarter have been aged between 10 and 19 years. Figure 14 shows the age distributions of cyclist fatalities in Queensland by gender. The long-term age distribution of cyclist fatalities in Queensland between 1991 and 2009 was similar for both male and female fatalities. The peak age groups for total number of fatalities were the 15-19 and 20-24 years age groups. These age groups do however correspond with relatively high levels of use of bicycles, particularly in a road environment.

4.3.2.1 Characteristics of fatal bicycle crashes

From 1991 to 2009, more than 85% of cyclist fatalities occurred in multiple-vehicle collisions (89.8% Australia, 86.5% Australia). Analysis of fatal cyclist crashes between

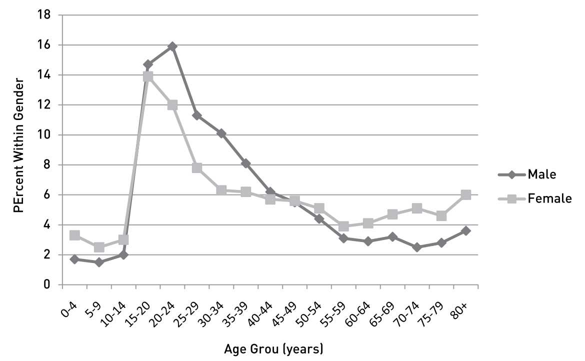

Figure 14. Age distribution of cyclist fatalities by gender, Queensland, 1991-2009. Source: Australian Road Fatality Statistics Database.

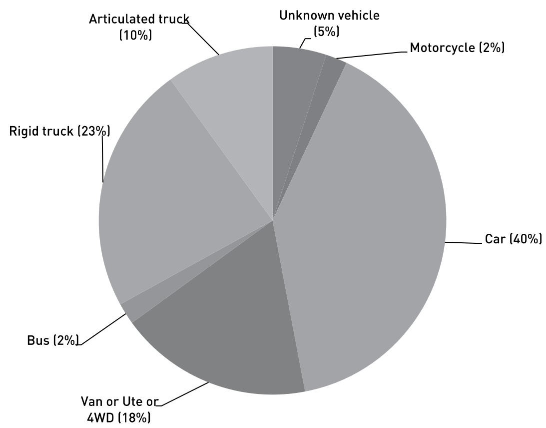

Figure 15. Crashes involving a motor vehicle in which a cyclist was killed, Australia, 1996 to 2000; proportions of each vehicle type. From ATSB (2006).

1996 and 2000 identified cars as the most frequent vehicular counterpart (ATSB, 2006). It should also be noted that 33% of all fatal crashes involving another vehicle involved an articulated or rigid truck (see Figure 15). The latest ABS Survey of Motor Vehicle Usage (ABS, 2008) notes that rigid trucks and articulated trucks together only accounted for approximately 7% of all kilometres travelled on Australian roads in 2007. Taken together, these figures indicate a substantial over-representation of heavy vehicles among fatal, multi-vehicle cyclist crashes.

For the years 1991 to 2005, most cyclists were killed in crashes in 60 km/h speed zones, with the next largest proportion being killed in 100 km/h speed zones (ATSB, 1996; see Table 22 below). In 2001-05, the percentage killed in 50 km/h speed zones increased and the percentage killed in 60 km/h speed zones decreased, probably reflecting changes in speed zoning practices.

Table 22. Cyclists killed in road crashes, Australia, 1991 to 2005 by speed limit at crash site. Source: ATSB.

Speed limit (km/h)	Time period 1991-95 Count	%	1996-2000 Count	%	2000-05 Count	%
20	1	0.4	0	0.0	0	0.0
25	0	0.0	1	0.4	0	0.0
40	1	0.4	2	0.9	1	0.4
50	0	0.0	4	1.8	34	17.9
60	138	55.0	95	42.4	66	34.7
70	12	4.8	18	8.0	13	6.8
75	4	1.6	0	0.0	0	0.0
80	19	7.6	29	12.9	20	10.5
90	3	1.2	2	0.9	1	0.5
100	65	25.9	50	22.3	39	20.5
110	5	2.0	14	6.3	11	5.8
Unlimited	1	0.4	0	0.0	1	0.5
Unknown	2	0.8	9	4.0	4	2.1
Total	251	100.0	224	100.0	190	100.0

4.3.3 Helmets and bicycle fatalities

Figure 16 below shows that the number of cyclists killed per year has approximately halved since 1991 (when helmet legislation was introduced in most jurisdictions). Figure 17 shows that the reduction in cyclist fatalities in the years following the introduction of the helmet wearing legislation was proportionally greater than for all road users, supporting the view that this related to the introduction of helmet legislation, rather than general road safety improvements.

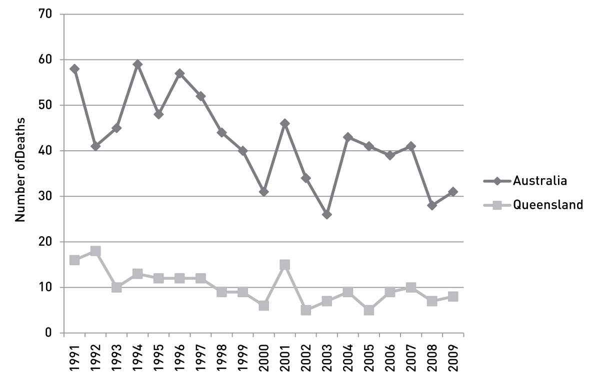

Figure 16. Numbers of cyclist (rider and pillion) fatalities in Australia and Queensland from 1991 to 2009. Source: Australian Road Fatality Statistics Database.

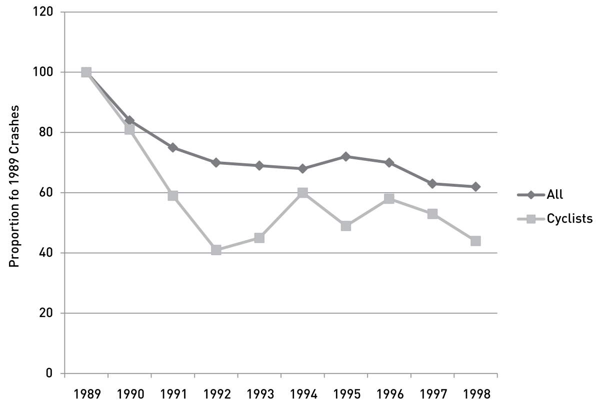

Figure 17. Proportion of 1989 fatal crashes for all road users and cyclists - Australia.

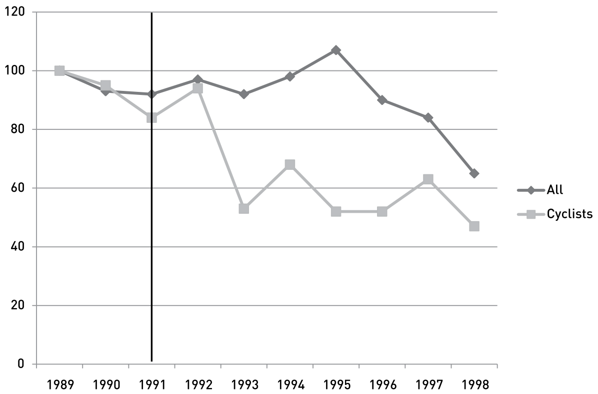

Figure 18. Proportion of 1989 fatal crashes for all road users and cyclists - Queensland.

The relevant figure for Queensland only (Figure 18 above) shows that the fall in cyclist fatalities relative to all road users occurred when the penalty for not wearing a helmet was introduced at the beginning of 1993, rather than when the legislation was introduced on 1 July 1991.

4.3.3.1 Helmet status of fatally injured cyclists

The ATSB (2006) report "Deaths of cyclists due to road crashes" provides information on helmet status of cyclists killed between 1996 and 2000. Helmet wearing rates for cyclist fatalities in Australia between 1996 and 2000 showed a substantial proportion of cases not wearing helmets. While the comparative proportion of non use between males and female was similar when considering all cases, the proportion of female fatalities not wearing a helmet was actually higher for cases with a known helmet wearing status (see Table 23 below).

Table 23. Helmet wearing by male and female fatally injured cyclists.

Gender	% not wearing helmet	% not wearing helmet excl. unknown helmet status fatalities
Male	32.1%	38.7%
Female	31.4%	45.8%
Total	32.0%	39.7%

Source: Deaths of cyclists due to road crashes - ATSB (2006).

Table 24. Number and percentage of fatally injured cyclists not wearing helmets.

Age Group	Not Worn	Total	% Not worn
5-9	7	15	46.7%
10-19	29	62	46.8%
20-29	10	30	33.3%
30-49	15	50	30.0%
50-64	4	31	12.9%
65+	6	34	17.6%

Significant variation in helmet wearing was also seen depending on age group. Children and young people aged 19 years and under were considerably more likely to not wear a helmet, with a steady decrease in the rates of helmet non-use with increasing age (see Table 24 above).

4.4 Analyse hospitalisation data to determine the extent of injuries to cyclists with and without helmets

4.4.1 Data set and its limitations

It was not possible to obtain the necessary approvals to access hospitalisation data (presentations and admissions) within the short timeframe available for this research. Therefore the task was undertaken by examining group level data in reports from the Australian Institute of Health and Welfare (AIHW):

- Hospital Separations Due to Injury and Poisoning, Australia, 2003-04 (Berry & Harrison, 2007);
- Hospital Separations Due to Injury and Poisoning, Australia, 2004-05 (Bradley & Harrison, 2008);
- Serious Injury Due to Land Transport Accidents, Australia, 2005-06 (Berry & Harrison, 2008); and,
- Serious Injury Due to Land Transport Accidents, Australia, 2006-07 (Henley & Harrison, 2009).

and the Queensland Trauma Registry (QTR)

- Description of Serious Injury Throughout Queensland, 2007 (Dallow, Lang, Harvey, Pollard & Bellamy, 2009b) and 2008 (Dallow, Lang, Harvey, Pollard & Bellamy, 2010b);
- Serious Injury Due to Road Traffic Crashes in Queensland, 2007 (Dallow, Lang, Harvey, Pollard & Bellamy, 2010c) and 2008 (Dallow, Lang, Harvey, Pollard & Bellamy, 2010d); and,
- A Summary of Paediatric Injuries Treated in Queensland, 2007 (Dallow, Lang, Harvey, Pollard & Bellamy, 2009a) and 2008 (Dallow, Lang, Harvey, Pollard & Bellamy, 2010a).

The Australian Institute of Health and Welfare series of reports on serious injury due to land transport accidents provides summaries of Queensland and Australian numbers and characteristics of bicyclists admitted to hospital for the years 2003-2004, 2005-2006 and 2006-2007. Where data are not provided specifically for Queensland, Australian data will be used. Given that the characteristics of cyclists and cycling are likely to be similar across Australian states, this information is likely to be a useful approach in the short term.

Given the reliance on these published reports, there are a number of limitations that need to be taken into account when drawing conclusions from such data. First and foremost in a discussion of the effectiveness of bicycle helmets, it should be noted that the datasets from which these reports are created do not record the helmet use of injured persons. Direct comparisons of the outcomes of injured persons wearing or not wearing helmets are therefore not possible.

Additional information over and above that available in police-reported crash data can however be gained from hospital records. Most notably, crashes and injuries which occur away from public roads are recorded in hospitalisation data. This has implications for the effectiveness of helmet legislation in terms of its applicability to riding on private property. Hospitalisation data records this in terms of injuries occurring in 'non-traffic' and 'traffic' contexts. 'Non-traffic' incidents are those occurring entirely away from a public road or highway, while 'traffic' incidents are those occurring in such places.

Detailed injury diagnoses are also available in hospital data (as sourced from medical charts), which are not typically available in police reported crash data.

4.4.2 Numbers and characteristics of bicyclist hospital admissions

A consistently high number of hospitalisations each year in Australia can be attributed to pedal cyclists. Approximately 17% of all Queensland land transport hospitalisations for the financial years of 2005/06 and 2006/07 were due to pedal cyclists (Berry & Harrison, 2008; Henley & Harrison, 2009). To better understand the potential effect of helmets on bicycling injury, the current patterns of injury among bicyclists needs to be better understood. Detailed information at the state level for Queensland is not typically reported.

Bicyclist hospitalisations were evenly split between traffic and non-traffic contexts as shown in Table 25 below.

Table 25. Numbers and percentages of cyclists hospitalised across Australia from traffic and non-traffic land transport accidents. Data from AIHW reports.

	Non-traffic		Traffic		Unspecified		Total	
Year	n	%	N	%	N	%	n	%
2003/04	3,966	49.9	3,686	46.4	289	3.6	7,941	100.0
2004/05	4,260	49.4	4,051	47.0	308	3.6	8,619	100.0
2005/06	4,129	46.8	4,370	49.6	315	3.6	8,814	100.0
2006/07	4,180	45.2	4,789	51.8	277	3.0	9,246	100.0
Total	16,535	47.8	16,896	48.8	1,189	3.4	34,620	100.0

Although the exact place where an injury occurs is often not specified in the hospitalisation data, indications can be seen from the valid data (see Table 26). This distribution additionally changes depending on the age group of injured cyclists. Two major points should be taken from the data. Firstly, while a large proportion of bicyclist injuries to very young children 4 years or under occur at home, injuries to 5-17 year olds and those over 18 years of age occurred much more frequently in a street/highway location. Secondly, of all injuries, 0-4 year olds accounted for 3% of injuries, 5-17 year olds 48% and those over 18 years 49%.

Table 26. Numbers and percentages of cyclists hospitalised across Australia in 2006/07 according to place of accident (includes traffic and non-traffic land transport accidents). Data from Henley & Harrison (2009).

	0-4			5-17			18+	
Place	N	%		n	%		n	%
Street and highway	22	22.0		1077	61.6		2558	88.5
Roadway	19	19.0		906	51.9		2248	77.8
Sports and athletics area	0	0.0		354	20.3		141	4.9
Forest, beach, area of water, countryside	0	0.0		61	3.5		133	4.6
Other/unspecified location in home	64	64.0		180	10.3		28	1.0
Driveway	7	7.0		27	1.5		13	0.4
Parking place	0	0.0		8	0.5		11	0.4
Farm	*	*		10	0.6		*	*
School	6	6.0		30	1.7		*	*
Known total	100	100.0		1 747	100.0		2 890	100.0
Other specified place	12	4.5		186	4.2		136	3.0
Unspecified place	157	58.4		2 470	56.1		1 548	33.8
Total	269	100.0		4 403	100.0		4 574	100.0

* Cells with small counts are suppressed.

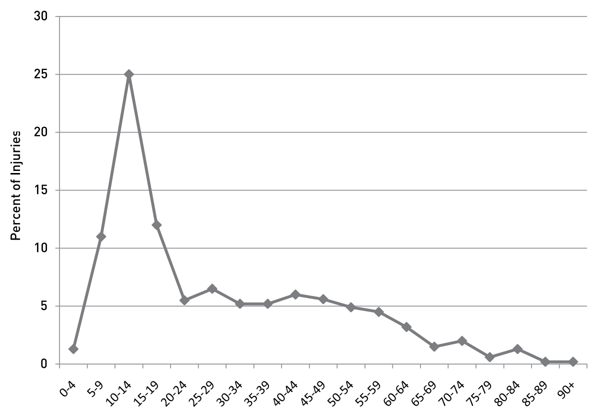

Figure 19. Queensland traffic cyclist hospitalisations by age group, 2007-2008. Source: QTR 2007, 2008.

The age distribution of cyclists injured in Queensland in a traffic context for the years 2007 and 2008 is shown above in Figure 19.

Understanding the circumstances of crashes that result in the hospitalisation of bicyclists is likewise important, particularly in relation to the vulnerability of cyclists. Table 27 below describes the mechanism of injury (e.g., the counterpart involved in the crash) by traffic status.

In both traffic and non-traffic injuries, non-collision incidents were the most common, though considerably more common among non-traffic injuries (88.2% of specified non-traffic injuries vs. 52.0% of specified traffic injuries). Over 95% of all non-traffic injuries with a specified mechanism did not involve another vehicle, while this was the case in only 58% of traffic injuries with a specified mechanism. Bicyclist injuries due to a collision in a traffic context most frequently involved a 'car, pickup, truck or van,' accounting for 34% of all injuries with a specified mechanism and 83% of all collision incidents with a specified mechanism.

4.4.3 Head injuries to bicyclists admitted to hospital

As stated in the introduction to this section, helmet use is not recorded against injury cases for hospitalisation data. Indications of the potential effect of bicycle helmets can however be inferred from the proportion of head injuries present among injured casualties.

Table 27. Pedal cyclist hospitalisations by traffic status and mechanism of injury, Australia, 2006/07.

	Non-traffic			Traffic		
Mechanism of injury	N	%	% specified	N	%	% specified
Non-collision	3,177	76.0	88.2	1,605	33.5	52.0
Fixed/stationary object	271	6.5	7.5	199	4.2	6.4
Pedal cyclist	87	2.1	2.4	132	2.7	4.3
Car, pickup, truck, van	32	0.8	0.9	1,064	22.2	34.4
Pedestrian or animal	20	0.5	0.6	27	0.6	0.9
Other non-motor	9	0.2	0.2	*	*	*
Two or 3 wheel motorcycle	5	0.1	0.1	9	0.2	0.3
Heavy vehicle or bus	0	0.0	0.0	48	1.0	1.6
Railway	0	0.0	0.0	*	*	*
Specified total	3,601	86.1	100.0	3,089	64.5	100.0
Other and unspecified transport	579	13.9	-	1,700	35.5	-
Total	4,180	100.0	-	4,789	100.0	-

* Cells with small counts are suppressed

The Queensland Trauma Registry annual reports of serious injury in Queensland for 2007 and 2008 both showed that head injuries (across all trauma patients, not just those in road traffic crashes) were more often represented in hospital admissions lasting 15 days or longer as compared to injuries to the thorax, abdomen or extremities. This is in line with a number of research studies which have identified an elevated risk of death among head-injured motorcyclists, and injured persons generally (Ankarath et al., 2002; Gennarelli, Champion, Sacco, Copes, & Alves, 1989).

Australia-wide data in Table 28 below shows that head injuries were the second most common region of principal diagnosis (24.6% of hospitalised cyclists), behind shoulder/upper limb (43.4% of hospitalised cyclists).

Table 28. Body region of principal diagnosis and resultant patient days for cyclists admitted to hospital (traffic only), Australia 2005/06 - 2006/07 financial years.

	Injury		Patient days	
Body region	n	%	N	%
Head	2,253	24.6	6,932	25.3
Neck	208	2.3	1,076	3.9
Thorax	434	4.7	2,214	8.1
Abd/lower back/lumbar spine/pelvis	586	6.4	3,289	12.0
Shoulder/upper limb	3,971	43.4	6,802	24.8
Hip and thigh	446	4.9	2,699	9.8
Lower limb	1,187	13.0	4,206	15.3
Other injuries	74	0.8	219	0.8
Total	9,159	100.0	27,437	100.0

4.5 Review data for emergency department presentations by cyclists

In 2005, the Queensland Injury Surveillance Unit (QISU) issued a bulletin on "Bicycle Injury in Queensland" (Scott, Hockey, Barker & Pitt, 2005) that describes the pattern of bicycle related injuries that presented to emergency departments from 1998 to mid 2004 as extracted from the QISU database. Bicycles are associated with 7% of all injuries in children aged 5 to 9 years and 9% of all injuries in children aged 10 to 14 years.

Examination of nature and body location of injury data revealed that almost a third of injuries involved the upper limb (30%) while approximately one quarter involved injury to the head, neck or face (23%). Bicycle related head injuries accounted for 11% of presentations in 5 to 16 year old children.

The most common mechanism of injury reported was a fall (53%) followed by contact with a moving object (8%) and then contact with a static object (8%). A quarter of injuries resulted in a fracture followed by open wound (24%), superficial injury (19%), sprain or strain (14%) and intracranial injury (7%). Almost 30% of injuries involved the elbow, forearm, wrist or hand. 23% involved injury to the head, neck or face, and 22% involved injury to the knee, lower leg, ankle or foot. In school age children (5 to 16 years), 11% of all head injury presentations are bike related. Adults had more injuries to the shoulder than did children, who were more likely to have an injury to the forearm.

Most injuries do not involve a collision with a motor vehicle and are 'single vehicle' crashes. Of the crashes that involved another vehicle, 10% resulted in an intracranial injury compared to 7% overall.

The QISU bulletin notes that their emergency room data shows 6-8% of injuries resulting from a collision with another vehicle while Police-reported data show that 84% of bicycle crashes involve a collision with another vehicle. Thus emergency department data allows better capture of information about bicycle collisions not involving motor vehicles.

Scott et al. (2005) report bicycle related injury data from the Mater Children's Hospital which indicate that in the two years preceding the introduction of compulsory helmets in Queensland, head injuries made up 34% of admitted patients with bicycle injury, while in the 10 years following this introduction, the percentage fell to 17%. The authors note that over this period there was no change in practice for admitting head injured patients.

4.6 Conclusions from analyses of crash and hospital data

4.6.1 Conclusions from crash data

All of the crash data analysed was post-legislation and penalty (1993-2008) because reliable earlier data are not available. Thus the data analyses cannot provide information on whether the introduction of helmet legislation led to a reduction in the percentage of injured cyclists who had head injuries.

The crash data does not include off-road crashes and there is likely to be very substantial under-reporting of bicycle crashes not involving a motor vehicle. Riders who were not wearing helmets at the time may have been less likely to report the crash to Police, which may have resulted in the reported data tending to over-estimate helmet use.

4.6.1.1 Helmet use

Since 1993, the crash data shows that the percentage of injured cyclists who are recorded as wearing a helmet has remained much the same, while the percentage recorded not wearing a helmet has fallen and the percentage where helmet use is unknown has increased. Over time there has been a decrease in reported helmet use rates for minor injuries, while there has been a general trend to increasing helmet use rates for medical treatment and hospitalisation injuries. The helmet-use rates for fatal injuries continue to fluctuate over time because of the small numbers.

Recorded helmet use rates are highest (approximately 80%) among injured cyclists aged 25 years or older. Helmet use trends are the lower for younger riders, with similar rates for primary and secondary school aged children (5-11 group and 12-17 group).

Bicycle pillions are less likely to wear helmets than bicycle riders and are much more likely to suffer a head injury.

4.6.1.2 Head injuries

Injury severity was lower for cyclists wearing a helmet. The proportion of head injuries and facial injuries was lower for those riders who were wearing a helmet. Injuries to other body regions did not differ noticeably between helmeted and non-helmeted riders, except for shoulder and upper limb injuries.

It is difficult to draw conclusions regarding the injury patterns of young children (aged 0-4), due to the limited cases available. Both helmeted and non helmeted cyclists aged 0-4 demonstrated a high proportion of head injuries, while cyclists without helmets also had a higher proportion of lower limb injuries in this age group.

4.6.1.3 Crash and rider characteristics

The greatest proportion of fatal bicycle crashes occurs on roads where the speed limit is 60 km/h, followed by 100 km/h. However, it is important to note that bicycle fatalities and serious injuries have occurred when signed speeds are less than 40 km/h. The majority of crashes occur on roadways where the posted speed limit is 60 km/h, regardless of the cyclists' age. Younger riders (aged 11 years or younger) are less likely to be involved in crashes on roadways with higher speed limits (≥70 km/h), or with very low speed limits (<40 km/h).

The proportion of reported bicycle crashes that have resulted in fatalities and hospitalisations has increased over time which may reflect the increase in the proportion of cyclists aged 25 years or older involved in police reported crashes. The proportion of crashes involving cyclists aged 0-4 has remained steady while the proportion of cyclists aged 5-11, 12-17 and 18-24 in police reported crashes has decreased, with the most noticeable decline being the 12-17 age group.

4.6.2 Conclusions from Australia-wide fatality data

Bicycle fatality data are only available for on-road fatalities but the research evidence suggests that almost all bicycle fatalities occur on roads. Most cyclists killed are males in collisions with motor vehicles with 15-29 year olds being most commonly involved. The number of cyclists killed per year has approximately halved since the introduction of helmet legislation. The reduction in cyclist fatalities in the years following the introduction of the helmet wearing legislation was proportionally greater than for all road users, supporting the view that this related to the introduction of helmet legislation, rather than general road safety improvements. Information about helmet wearing by killed cyclists is only available for 1996 to 200 and shows that about a third of killed cyclists were not wearing a helmet. Wearing rates were lowest by cyclists aged under 20, with a steady increase with age.

Unfortunately, Australia-wide data on the role of head injuries in deaths and helmet wearing status have not been published for the period covering both before and after the introduction of the legislation. This limits the conclusions that can be drawn.

4.6.3 Conclusions from hospital data

Analysis of hospital admissions data showed that approximately 17% of all land transport hospitalisations in Queensland are cyclists, about half of these injured in on-road and about half injured in off-road crashes. Across Australia, about half of the cyclists hospitalised are children, who are more likely to have been injured in off-road crashes than adults. Even among on-road crashes, about half of the hospitalisations result from non-collision events (e.g. falling off the bike). Head injuries were the second most common principal diagnosis for cyclists admitted to hospital from on-road crashes, after shoulder/ upper limb injuries, but resulted in similar numbers of total patient days.

Similarly, emergency department data from the Queensland Injury Surveillance Unit reports injuries to the head, neck or face as second most common after injuries to the upper limb. Only 6-8% of emergency department presentations by cyclists result from a collision with a motor vehicle but these collisions are more likely to result in intracranial injury.

Data from the Mater Children's Hospital has shown that the percentage of cyclists admitted with head injury has halved since bicycle helmet legislation was introduced.

5. DISCUSSION OF RESULTS OF LITERATURE REVIEW AND ANALYSES OF CRASH AND HOSPITAL DATA

This section brings together the results from the literature review and the analyses of the crash and hospital data. It commences with a discussion of the limitations in what can be concluded from the research and the issues that underlie these limitations. It then goes on to discuss the general findings that are consistent across the published literature and the data analyses that have been presented in this report.

5.1 Limitations in the research

5.1.1 Alternative explanations of the results

For many of the issues addressed in this report, there continues to be controversy because of the difficulty in conducting research where the results can only be interpreted in one particular manner. The inability to randomly assign participants to conditions appears to be the underlying problem. It is not possible to assign participants to cycling or non-cycling conditions (or amounts of cycling) in order to conduct prospective studies of the effects of cycling on health. Similarly, participants are unable to be randomly assigned to the locations (roadway type, footpath, off-road facility etc) in which they will ride. Nor can they be assigned to helmet and non-helmet wearing conditions. The outcome of this constraint on research methodology is that the results can always be criticised as consequences of the type of rider that is involved, rather than the underlying issue. Therefore it can always be argued that the riders who wear helmets are somehow intrinsically safer riders than the ones who do not, or that those who ride on footpaths are somehow different than those who ride on the road or that people who chose to cycle would have been healthier anyway. While complicated research designs have been constructed to minimise the likelihood of alternative explanations, they still remain.

5.1.2 Difficulties in predicting the future

Another contributor to much of the controversy in the literature is the difficulty in predicting the future. For example, in order to estimate benefit-cost ratios for a range of interventions to influence cycling participation, assumptions must be made about likely changes in cycling related to not only the intervention but other independent effects (such as ageing of the population or fuel prices). Depending on the different scenarios chosen, these assumptions can result in widely different estimates of the outcomes. Yet it is difficult to judge which assumptions are reasonable and experts continue to disagree.

Another related problem occurs when trying to apply the results from an intervention that was implemented in one location in the past to the proposed implementation in another location. For example, how relevant are the reductions in cycling participation that occurred in Australia when mandatory helmet legislation was introduced 20 years ago to proposals to introduce similar legislation in other countries? Factors such as the level of traffic congestion, environmental and health concerns, and general level of road safety awareness and willingness to participate in self-protective behaviours may be very different.

This issue is also relevant in terms of the ability to apply results from the same jurisdiction across time. While the observational data shows that reductions in cycling accompanied the introduction of helmet legislation in Australia 20 years ago, this does not necessarily show that cycling participation is currently depressed by the legislation. Indeed, the surveys of attitudes throughout Australia suggest that helmet requirements play very little role in decisions not to cycle.

5.1.3 Difficulties in measuring the present

There are difficulties in measuring the health outcomes of cycling and the effects of a whole range of interventions that stem from poor data about what is happening now. Any calculation of risks or rates is beset by inadequacies in both the numerator and the denominator.

The interpretation of the crash and hospital data is made more complicated by the lack of completeness of reporting of bicycle incidents and injuries, both in scope and reporting rate. While hospital admissions data provides a general ability to count both on- and off-road injuries, there are still many cyclist admissions for which information about type of location is not specified. Even for those admissions where location is coded to the extent possible under the ICD-10-AM, the categories in that coding system are not always adequate for an understanding of the effects of particular types of bicycle and other road infrastructure on cyclist safety. For other levels of injury severity, the data is much poorer.

While there are very large issues with incident or injury data for cyclists, these are overshadowed by the poverty of exposure information. Details of who rides where, when and why are rarely available to the extent or in the form needed for comparison with the incident or injury data. This leads to rates often being calculated at a very macroscopic level, and those rates are arguably of limited value for any more specific purposes.

5.2 Comparing data analyses with the published research

5.2.1 Helmet effectiveness

A review of the most scientifically rigorous research concluded that bicycle helmets that meet national standards protect against head, brain, and facial injuries. Helmet wearing was associated with a 69% reduction in the likelihood of head or brain injury and a 74% reduction in the likelihood of severe brain injury. The benefit was the same whether a motor vehicle was involved in the crash or not. Helmet wearing reduced the likelihood of injury to the upper and mid-face by 65%.

Information from the Queensland Police-reported cyclist crash data for 1993-2008 (post-legislation) was analysed to assess whether it showed the same patterns. It should be noted that the Police-reported data has many limitations, as described in the previous chapter. The data comprises largely bicycle-motor vehicle collisions, there is significant under-reporting and the data on part of the body injured is reported by Police, rather than clinicians. Nevertheless, the numbers are large, they relate to Queensland crashes and are relatively timely.

The reductions in the likelihood of head injury calculated from the Queensland Police-reported data were similar to the conclusions of the Cochrane review. The Queensland data show reductions of 60% in the likelihood of head injury (69% in the literature), 53% for serious head injury (74% in the literature) and 58% for head and/or facial injury (65% for upper and mid-face in the literature) associated with wearing a helmet. If all riders for whom helmet status was unknown were assumed to have worn a helmet, there was little change in the estimated reduction. If it was assumed that all riders for whom helmet status was unknown did not wear helmets, then the size of the estimated reduction decreased by 12 to 21%.

The national hospital admissions data and the routine national road fatality data do not include information on helmet wearing status, so are of limited relevance to assessing helmet effectiveness. However, data from the Mater Children's Hospital has shown that the percentage of cyclists admitted with head injury has halved since bicycle helmet legislation was introduced.

5.2.2 Relative safety of different types of riding environments

In Australia, off-road riding contributes almost half of the hospitalisations as a result of bicycle crashes (Henley & Harrison, 2009) but there is relatively little research into these types of crashes and injuries. The hospital data suggests that relatively more bicycle crashes involving children occur off-road than on-road but little is known about helmet use in off-road riding or whether helmets are more or less beneficial in off- than on-road cycling. There is no existing data that clearly compares the safety of on- and off-road riding environments.

Even among on-road crashes, about half of the hospitalisations result from non-collision events (e.g. falling off the bike). It is likely that most bicycle injuries (both on- and off-road) relate to non-collision events, despite the greater representation of on-road collision events in fatalities. Thus, the protection that helmets offer in non-collision events supports their use in both on- and off-road riding environments.

Comparisons of the safety of different types of road and off-road riding environments are hampered by inadequate descriptions of the site of the incident and by lack of information about how much riding by what rider types occurs on that infrastructure. This is particularly problematic in relation to footpaths and off-road cycle paths.

5.2.3 Trends in cyclist injuries

According to the Australian Institute of Health and Welfare, the number of cyclists admitted to hospital in Queensland following a road traffic crash increased from 749 in 2003/04 to 824 in 2005/06 to 1,000 in 2006/07, an overall increase of 34%. Yet the same trend does not appear to have occurred in Queensland Police-reported cyclist crashes with the level of severity recorded as "hospitalisation". The average number of cyclist hospitalisation crashes across 2003 and 2004 was 277, with 311 across 2004 and 2005, 290 across 2005 and 2006 and 272 across 2006 and 2007. This corresponds to a reduction of about 2% across the time period.

The reasons underlying this discrepancy in trends between the hospital and police-reported data are unclear. There was no reduction in the frequency with which location was coded as "unspecified" in the hospital data. While police may have not have been accurate in their coding of injury severity, no increases in crashes resulting in medical treatment or minor injury were recorded, that could have led to fewer crashes being coded as "hospitalisation". It is possible that the rate of reporting of bicycle crashes to police may have dropped. This should be investigated further, because it would imply that police-reported crash data may be becoming less useful for monitoring and characterising on-road bicycle crashes.

5.3 Conclusions

There are a range of limitations to both the published research and the available crash and injury data. These limitations have fuelled controversy regarding the health outcomes of cycling and the effectiveness of bicycle helmets and bicycle helmet legislation. The limitations relate to the inability to randomly assign participants to treatments, difficulties in estimating what will happen in the future and poor data regarding the present.

Nevertheless, there are consistencies across the published research and the crash and hospital data analyses. The analysis of the Queensland Police-reported cyclist crash data showed similar reductions in the likelihood of head injury, serious head injury and head and/or facial injury to that reported in the Cochrane review of helmet effectiveness.

Both the published research and the hospital data analyses show that off-road bicycle crashes are very important, particularly for children and non-fatal injuries. The lack of inclusion of these crashes in the police-reported data and the lack of increase in bicycle crashes over time in the police-reported data (which is evident in the hospital data) suggests that reliance on the police-reported data may give only a patchy view of the number and characteristics of bicycle-related crash injuries.

6. CRITICAL EXAMINATION OF METHODOLOGY OF VOUKELATOS AND RISSEL PAPER

This section presents a critical examination of the methodology used by Voukelatos and Rissel (2010), including a review of:

1. The assumptions underlying the comparison of numbers of head versus arm injuries;
2. The assumptions underlying the use of admitted patient data;
3. The consistency of hospital admission practices for different injuries over time;
4. The consistency of hospital admission practices across age of injured person (including changes over time);
5. The relevance of New South Wales helmet use data to Queensland;
6. Whether Queensland hospital data showed the same trends as New South Wales; and,
7. The extent to which other programs influenced bicycle injury numbers and rates.

6.1 The assumptions underlying the comparison of head versus arm injuries

Voukelatos and Rissel (2010) used the ratio of the numbers of cyclist hospital separations where the principal injury was severe head injuries to the number of cyclist hospital separations where the principal injury was severe arm/hand injuries to provide an indicator of the effectiveness of helmet legislation in reducing head injuries. For simplicity, this will be referred to as "the ratio of head to arm injuries" in the remainder of this section.

They describe their rationale for taking this approach in the following way: "the analysis is based on the idea that even if the number of cyclists dropped over time, the relative injury rates (head versus arm) should remain unchanged unless some factor is differentially impacting on one type of injury – for example, helmet use reducing head injuries, but not affecting arm injuries. Arm injuries were chosen rather than leg injuries, as arm injuries are more closely located in relation to the upper torso and head" (p.50).

One reason for taking this approach was because direct evidence regarding whether or not a helmet was worn is not recorded in the hospital separations data, so the extent of injuries to helmeted and unhelmeted riders cannot be simply compared. The other reason, as they note, is to provide a comparison with another type of cyclist injury in order to be able to incorporate a measure that is sensitive to changes in the amount of cycling. Observing a drop in the number of cyclists with head injuries could be interpreted as an effect of less cycling, rather than necessarily due to a protective effect of helmet wearing.

However, there are a number of assumptions underlying the comparison of head and arm injuries that may affect their conclusions. The assumptions that are examined in this section are:

1. Use of ICD10 codes S00-S09 to characterise head injuries;
2. Using the ratio of head and arm injuries as an indicator of helmet effectiveness

6.1.1 Using ICD codes S00-S09 to characterise head injuries

The ICD-10-AM codes termed **Injury to the head** are S00–S09 as used by Voukelatos and Rissel (2010). These codes include injuries to the skull and brain, ear, eye, face, gum, jaw, oral cavity, palate, periocular area, scalp, temporomandibular joint area, tongue and tooth (but not burns to the head). These codes cover a much wider range of injuries than traumatic brain injury, which according to the US Centers for Disease Control and Prevention's case definition (cited in Thurman et al., 1995) includes only open wound of head, fracture of skull or facial bones, intracranial injury, crushing injury of head and other unspecified head injuries.

Thus the use of ICD-10-AM codes S00-S09 may include injuries to areas of the head and face that are not expected to be prevented by bicycle helmets. The research reviewed in Chapter 3 concluded that bicycle helmets can be effective in preventing traumatic injury and also appear to have the added benefit of reducing injuries to the upper parts of the head. Not surprisingly, since bicycle helmets provide no coverage of the face and chin (except for some specialist mountain bike helmets), they are not effective in preventing injuries to the lower parts of the head.

Therefore, the use of the ICD-10-AM codes S00-S09 by Voukelatos and Rissel (2010) may underestimate the effectiveness of bicycle helmets by including a range of injuries that are unlikely to be prevented by bicycle helmets.

6.1.2 Using the ratio of head and arm injuries as an indicator of helmet effectiveness

Voukelatos and Rissel (2010) present data in their Figure 1 that shows that the ratio of head to arm injuries differed as a function of age group. For cyclists aged 15-24 (a group known for low helmet wearing rates), the ratio was just greater than one, while the ratio was less than one for other age groups (including 0-14 year olds where the total number of both types of injuries was greatest). This suggests that any change in the age distribution of cyclists hospitalised could affect the overall ratio of head to arm injuries.

6.2 The assumptions underlying the use of admitted patient data

The use of admitted patient data to measure the effectiveness of an intervention designed to reduce injury has advantages and disadvantages. It is systematically and repeatedly collected across the whole of the State and therefore usually has sufficient numbers to allow robust analyses. It also suffers less from the problem of under-reporting of on-road crashes in Police databases (especially crashes that do not involve motor vehicles) and the complete lack of off-road crashes in Police databases.

The first disadvantage of using admitted patient data is that by its very nature, it does not contain any information about the cyclists who were not sufficiently injured to be admitted to hospital (or those that died before reaching hospital). It may be these very cyclists who are benefiting from wearing helmets. This is part of a general methodological concern with using data where injury is the inclusion criteria (e.g. only including people who have been admitted to hospital) to evaluate an injury reduction measure.

A current ARC-funded study of the performance of bicycle and motorcycle helmets at the University of New South Wales (McIntosh et al., 2010) has taken a different approach which is arguably more methodologically sound. Their inclusion criterion was involvement in a bicycle crash in which a helmet was worn and the helmet contacted an object (regardless of whether injury occurred). They found that the ratio of head to upper limb injuries differed as a function of maximum injury severity (MAIS). For the lowest level of injury (MAIS=0), 5.1% of cyclists had a head injury and 15.6% had an upper limb injury (a head to arm ratio of about 0.3). For MAIS=1, 11.5% of cyclists had a head injury and 44.8% had an upper limb injury (a ratio of about 0.3). However, for MAIS=2 injuries (common in hospital admissions), 35.4% of cyclists had a head injury and 38.5% had an upper limb injury (a ratio of about 0.9). Despite the cyclists recruited by McIntosh et al. (2010) being largely adults, this ratio of 0.9 is very similar to the all ages ratios reported by Voukelatos and Rissel (2010) since 2001.

This research shows that the head to arm ratio of injuries differs as a function of the injury severity of the sample of cyclists analysed. Therefore this ratio may not be a reliable measure of the effectiveness of bicycle helmet legislation in reducing head injuries.

The second disadvantage of the approach taken by Voukelatos and Rissel (2010) is that it counts numbers of hospitalised cyclists for head and arm injuries but does not formally take injury severity into consideration. Carr, Skalova and Cameron (1995) demonstrated that the severity of head injuries for crash-involved bicyclists declined after the introduction of helmet wearing legislation. The proportion of admitted cyclists with the highest (critical) head injury severity remained unchanged in the post-legislation period. There were, however, clear reductions in the proportion of admitted bicyclists with head injuries in the serious and severe categories (40% for all admitted bicyclists and 46% for admitted bicyclists where a motor vehicle was involved in the crash).

6.3 The consistency of hospital admission practices over time

The approach taken by Voukelatos and Rissel (2010) assumes that the likelihood an injured person will be admitted to hospital, given a particular type and severity of injury, will be constant over time. However, triage practices and hospital policies change over time and there is evidence that this has occurred in relation to head injuries. For example, the third year review of the Victorian bicycle helmet legislation (Newstead, Cameron, Gantzer & Finch, 1994) suggested that there had been an upturn in the proportion of hospitalised cyclists sustaining head injuries but it was proposed that this may have resulted from changes in funding arrangements for publicly-funded hospitals. These changes effectively encouraged hospitals to admit head-injured patients, rather than treating them in the Emergency Department and then sending them home.

Thus, there may have been increases in the likelihood that head injured cyclists would be admitted during the period 1988-89 to 2007-08 that may have masked reductions in head injury severity resulting from bicycle helmet wearing. This would have made it more difficult for Voukelatos and Rissel (2010) to detect a reduction in the head to arm ratio and therefore to find a benefit of bicycle helmet legislation.

6.4 The consistency of hospital admission practices across age

The likelihood that an injured person will be admitted to hospital, given a particular type and severity of injury, may also vary as a function of age (and this may also change over time). Parents may be more likely to take a young child to hospital after a head impact "to get him checked out", than they would be for an older child ("leave me alone, I'm OK") or for themselves. Once a person arrives at the Emergency Department, the likelihood of admission for a head injury may be greater for younger children (even if only for observation) than for older persons (QISU, personal communication). Any changes in these practices over time, as well as in the age distribution of cyclists sustaining impacts to the head, could lead to changes in the head to arm injuries ratio calculated by Voukelatos and Rissel.

6.5 The relevance of New South Wales helmet use data to Queensland

Voukelatos and Rissel (2010) present helmet use data from a report by Smith and Milthorpe (1993) for the NSW Roads and Traffic Authority. In the caption of their Figure 2, Voukelatos and Rissel describe the data as "self-reported helmet use" but in the reference list, the title of Smith and Milthorpe's publication is "An observational study of law compliance and helmet wearing by bicyclists in New South Wales – 1993". We have been unable to obtain a copy of Smith and Milthorpe's report so are unable to clarify the nature of their methods but references to this report in other documents suggest that data was collected at specific sites each year, supporting the view that it may have been observational data but not completely resolving this issue.

Regardless of how the data were collected, they show surprisingly low wearing rates in 1991/92 (about 5% for riders aged under 16 and 15% for those aged over 16) which increased to between 75 and 85% in 1993/94 and 1995/96.

Observational data from other States have shown much higher rates of helmet wearing before and immediately following the introduction of the law (see Section 3.5.1). In Queensland, wearing rates for primary and secondary school students were 59% and 13% with adult rates of 21-22% when measured 3 months before the legislation came into effect (King & Fraine, 1994). Before the enactment of mandatory bicycle helmet wearing legislation in Victoria in July 1990, Melbourne metropolitan wearing rates were 65% for 5-11 year olds, 21% for 12 to 17 year olds and 36% for adults (Finch et al., 1993). These interstate data call the accuracy and generalisability of the NSW helmet wearing data into question.

6.6 Whether Queensland hospital data showed the same trends

We do not currently have access to Queensland hospital data prior to 2003 so we are unable to answer this question directly. The very large variability in the numbers of cases of head and arm injuries each year (even when summed over all ages) gives one cause for concern in interpreting the ratios that are calculated. For example, from 1988-89 to 1989-90, the number of cases of head injury increased from 702 to 770 while the number of arm injuries increased from 499 to 666.

6.7 The extent to which other programs influenced bicycle injury trends

Voukelatos and Rissel (2010) state that "it is most likely that a series of changes in road safety and conditions before 1991 contributed to a generally safer road environment, which benefited people cycling as well as other road users" (p.54). In NSW, these changes included the introduction of random breath testing in 1982, intensive road safety advertising in 1989 and speed cameras programs in 1990.

A Victorian study has identified that cyclist injuries were reduced by general road safety measures, but more so by helmet legislation. Carr, Skalova and Cameron (1995) found that the number of hospital admissions for bicycle crashes was 40% below the number expected on the basis of pre-legislation trends. The modeling process, which accounted for other road safety-related factors, suggested that the reduction in bicycle admissions was largely due to the helmet legislation

It is important to note that the bicyclist hospital separations analysed by Voukelatos and Rissel (2010) resulted from both on- and off-road crashes. Clearly, road safety programs that targeted motorist behaviour (such as drink driving and speeding) are unlikely to have affected the off-road crashes. While the authors do not present data on the breakdown of crash locations, current hospital admission data suggests that about half of the cyclists admitted to hospital were riding off-road. Thus, the claim by Voukelatos and Rissel that the reductions before 1991 resulted from changes in general road safety is weakened by their inclusion of cyclist injuries resulting from off-road crashes.

6.8 Conclusions

There are a number of assumptions made in the methodology adopted by Voukelatos and Rissel (2010) that are not supported by findings from other research. While the impact of these methodological implications cannot always be easily assessed, their overall result is to call into question the conclusion that "it is likely that factors other than the mandatory helmet legislation reduced head injuries among cyclists" (p.50).

7. CRITICAL EXAMINATION OF THE POSSIBILITY OF A SEGMENTED APPROACH TO MANDATORY HELMET LEGISLATION

This section examines the potential consequences of moving from universal to segmented mandatory helmet legislation. It briefly describes the segmented approaches (e.g. age, location) that have been taken in other jurisdictions and any evaluations of their outcomes. It also includes information from Section 4 regarding injury patterns and severities to provide a background to the potential effects if such segmented legislation were to be applied in Queensland. Practical issues such as interconnectivity of networks will also be discussed.

From the literature, a small number of segmented approaches to helmet legislation have been identified based on what has occurred in other countries or has been suggested by others. This section then examines the potential effects of moving from universal to segmented helmet legislation on helmet use, head injuries and amount of cycling. It is important to note that these differences may not be simply the reverse of the effects of introducing legislation. The segmented approaches described here are:

1. Mandatory helmet wearing for children only;
2. Mandatory helmet wearing when riding on roads with a speed limit of over 40 km/h; and,
3. Mandatory helmet wearing when riding on roads but not on bicycle paths or footpaths or off-road.

7.1 Direct and indirect effects of segmented approaches

Segmented approaches to bicycle helmet legislation clearly have direct effects on the behaviour and safety of the groups or areas specifically mentioned in the legislation, but they can also have indirect effects that may be unanticipated but important. For example, bicycle helmet legislation applying only to riders aged under 18 would have the direct effect of increasing helmet wearing among that group but not the older group. However, it is likely that riders aged under 18 (and their parents and peers) would consider that helmets are not as important or necessary if they are not required by older riders. This may lead to a lower wearing rate by young riders under segmented legislation than under universal legislation. This would be an example of an indirect effect of a segmented approach to helmet legislation.

While there is little specific evidence that can be used to confirm the existence and magnitude of indirect effects of a segmented approach, there are parallels from other areas of road safety that confirm that such effects are likely. In some US states where universal motorcycle helmet laws have been replaced by laws requiring use by riders aged under 18 only, helmet wearing rates for under 18s have dropped (Preusser, Hedland & Ulmer, 2000; Ulmer & Northrup, 2005).

Indirect effects may also be found for requiring helmets only for some riding environments. For example if helmets are not required on off-road bicycle paths, then a rider may choose to not wear a helmet for a trip where most (but not all) of the travel is on a bicycle path. There will almost always be a part of a trip that requires on-road travel, because few people live directly abutting bicycle paths. Similarly, riders may intend to ride only in a type of location where helmets are not mandatory, but find that construction work (or some other unexpected change to access) requires a different route to be taken or that the type of route does not allow them to access their destination.

7.2 Segmented approaches in other jurisdictions

7.2.1 Age segmentation of bicycle helmet legislation

The literature review in Section 3 of this report shows that bicycle helmet legislation applies to children only in many international jurisdictions. This includes various states (Oregon, Florida) and local areas in the United States; the Canadian provinces of Ontario and Alberta; Iceland; the Czech Republic; and Japan. The legislation applies to children under 16 in the two US jurisdictions, Iceland and the Czech Republic; under 18 in the two Canadian provinces; and under 13 in Japan.

Unfortunately, the published research focuses on helmet wearing rates for children in those jurisdictions, and does not provide information on adult helmet wearing rates. In addition, many of the studies of wearing rates for children before and after introduction of the legislation collected after data soon after the legislation was introduced. This gives no information on how long-lasting any increase was and also means that much of the data is 10 or more years old.

7.2.2 Location-based segmentation of bicycle helmet legislation

Location-based segmentation of bicycle helmet legislation is less common than age-based segmentation. Helmet legislation applies on roads but not off-road in New Zealand and the Northern Territory. In Spain, helmets are not required when cycling in towns or when climbing steep hills. No published research was found that examined the effects of location-based segmentation.

7.3 Potential effects of segmented legislation in Queensland

In this section, an attempt is made to estimate the potential effects of segmented legislation based on available data (which is often patchy) and a range of assumptions. As noted earlier in this report, there is considerable under-reporting of on-road bicycle crashes to Police, particularly those that do not involve motor vehicles. Yet the police data is the only large database that contains information on whether the rider was wearing a helmet and whether head injuries were sustained (even if the reliability of this data has been questioned). Hospital admission data provides an indicator of the potential true number of on-road cyclist injuries requiring hospital admission and of the ratio of on- to off-road cyclist injury admissions. Thus, the estimates of potential outcomes of segmented legislation rely on both types of data.

Two estimates of the effects are given for each type of segmented legislation. The first assumes that segmented legislation would lead to zero use of helmets among the non-mandatory group. The second estimate assumes that segmented legislation would result in a halving in the current helmet wearing rate among the non-mandatory group. A rough estimate is also provided of the possible indirect effect, that is, a reduction in the helmet wearing rate by members of the group still required to use helmets. For comparison, the estimates are summarised in Table 33 at the end of this section.

7.3.1 Mandatory helmet wearing for children only

For the purposes of identifying the potential effects of such a change in Queensland, it has been assumed that the legislation would require helmet wearing by riders and pillions aged under 18 only. The potential effects of such a change on injuries in on-road crashes and in off-road crashes are calculated separately, before being combined.

7.3.1.1 Effects on injuries in on-road crashes

Each of the sources of data examined give comparable estimates of the proportions of child and adult cyclists injured. The percentage of cyclists aged 18 and over in Police-reported crashes in Queensland has increased from 59% of crashed riders over 1993-2008 to about 70% in 2004-08. It is unclear whether this difference reflects an increase in risk for adult cyclists or an increase in the percentage of cyclists who are adults.

Australia-wide data (Henley & Harrison, 2009) for cyclists admitted to hospital shows similar numbers of cyclists aged under 18 and 18 and over. It also shows similar numbers of traffic and non-traffic causes for these hospitalisations (see Table 29). While there is no break-down of traffic/non-traffic by adult/child provided, an earlier table in our report (Table 30) shows place of occurrence for cyclists aged 0-4, 5-17 and 18+. Unfortunately, place was "unspecified" or "other specified" for more than 60% of child cyclists and more than 35% of adult cyclists. Where place was recorded as known, 60% of child cyclists had been injured on a street or highway, compared with 88.5% of adult cyclists. Reconciling the data from Tables 29 and 30 indicates that about 65% of hospitalisations of adults and 35% of hospital admissions of child cyclists relate to on-road injuries.

The Queensland Trauma Registry reports present age groups such that the cut-off can only be made at age 20 (Dallow et al., 2010c, d). These reports show that 66.3% of cyclists in road traffic crashes entered in the Trauma Registry in 2007 and 2008 were aged 20 and over.

Following the Australia-wide hospital data, the analyses below will assume that 65% of cyclists injured in road crashes are aged 18 and over.

There is no clear difference in severity between Police-reported on-road crashes of cyclists aged under and over 18. While most of the fatalities in Queensland in the five years 2004-08 were adults (35/42), the fatalities comprise a relatively small proportion of total crashes and similar percentages of child and adult rider crashes were coded as hospitalisation crashes.

Police-reported crashes show a somewhat lower incidence of head and face injuries in cyclists aged 18 years and over, which is consistent with the higher rate of helmet wearing in the same data (see Table 29).

Table 29. Numbers and percentages of head and face injuries and helmet wearing rates in Police-reported bicycle crashes according to age of cyclist. 1993-2008.

	Age <18 years		Age 18 years or over	
Reported injury	Count	%	Count	%
Head	559	10.2	625	7.7
Face	612	11.1	749	9.29
Head and/or Face	1130	20.5	1313	16.1
Helmet worn	3545	64.4	6509	80.0

Based on current helmet wearing rates of 80% for adult cyclists (according to the police-reported crash data in Table 29) and the 70% reduction in head injuries concluded by the Cochrane Review (Thompson et al., 2009), the proportion of on-road head injuries sustained now compared to the situation if no adult riders wore helmets can be estimated as follows:

Proportion of head injuries cf no wearing

= proportion worn x head injuries despite wearing + proportion not worn x head injuries if not worn

$= .8 \times (1 - .7) + .2 \times 1$

$= 0.44$

Thus, if the helmet wearing rate for adults fell to zero as a result of requiring helmets only for children, then a 56% increase in head injuries to adults would be expected. Assuming that adults comprise 65% of cyclists injured in on-road crashes, this would correspond to an overall 36% increase in head injuries to all cyclists injured in on-road crashes.

Similarly, if the helmet wearing rate for adults fell to half of its current rate (i.e. to 40%) as a result of requiring helmets only for children, the proportion of head injuries (where 1 is zero wearing) would increase from 0.44 to 0.72. Assuming that adults comprise 65% of cyclists in on-road crashes, this would correspond to an overall 18% increase in head injuries to all cyclists injured in on-road crashes.

As noted in Section 7.1, the helmet wearing rate for children could fall as a result of changing from universal to segmented legislation. If, for example, the helmet wearing rate for children fell from 65% to 50%, then a 10% increase in head injuries to children would be expected. Assuming that children comprise 35% of cyclists in on-road crashes, this would correspond to an overall 3% increase in head injuries to all cyclists injured in on-road crashes.

The above analyses assume that there is no increase in the number of adult cyclist crashes on road associated with any increase in cycling accompanying the removal of the universal legislation.

7.3.1.2 Effects on injuries in off-road crashes

Following from the previous section, it is assumed that 35% of cyclists injured in off-road crashes are adults and that 50% of cyclists injured are in off-road crashes.

There is no evidence that helmet wearing rates differ between on- and off-road crashes. For this reason, the estimates below assume that they are the same and use the wearing rates in the police-reported crashes shown in Table 29.

Based on current helmet wearing rates of 80% for adult cyclists and the 70% reduction in head injuries concluded by the Cochrane Review (Thompson et al., 2009), the proportion of off-road head injuries sustained now compared to the situation if no adult riders wore helmets is 0.44, because it is based on the same proportions as in the Police-reported on-road crashes. Thus, if the helmet wearing rate for adults fell to zero as a result of requiring helmets only for children, then a 56% increase in off-road head injuries to adults would be expected. Given that adults are assumed to comprise 35% of cyclists in off-road crashes, this would correspond to an overall 20% increase in head injuries to all cyclists hospitalised following off-road crashes.

Similarly, if the helmet wearing rate for adults fell to half of its current rate (i.e. to 40%) as a result of requiring helmets only for children, the proportion of head injuries (where 1 is zero wearing) would increase to 0.72. If adults are assumed to comprise 35% of cyclists in off-road crashes, this would correspond to an overall 10% increase in head injuries to all cyclists hospitalised following off-road crashes.

As noted in Section 7.1, the helmet wearing rate for children could fall as a result of changing from universal to segmented legislation. If, for example, the helmet wearing rate for children fell from 65% to 50%, then a 10% increase in head injuries to children would be expected. Given that children comprise 65% of cyclists hospitalised following off-road crashes, this would correspond to an overall 6% increase in head injuries to all cyclists hospitalised following off-road crashes.

The above analyses assume that there is no increase in the number of off-road adult cyclist hospitalisations associated with any increase in cycling accompanying the removal of the universal legislation.

7.3.2 Mandatory helmet wearing when riding on roads with a speed limit of over 40 km/h

A requirement for mandatory helmet wearing only when riding on roads with a speed limit of over 40 km/h would remove the requirement to wear a helmet on roads with lower speed limits and when riding not on public roads, including bicycle paths.

7.3.2.1 Effects on injuries in on-road crashes

It is difficult to assess the potential future effects of requiring helmet wearing on roads with speed limits over 40 km/h only because much of the available information is not up-to-date and much of the introduction of 40 km/h speed zones in Queensland has been very recent. The Police-reported data for 1993-2008 shows that 3.3% of cyclist crashes occurred on roads with speed limits of 40 km/h or less. As noted in the earlier chapter, in 2000-2008 this increased only slightly to 3.8%, so there is no evidence of a discernible increase in crashes in these low speed zones in recent years.

Table 30 summarises the numbers and percentages of cyclists with reported head and face injuries and helmet wearing rates in speed zones of 40 km/h or less compared with higher speed zones during 1993-2008. Helmet wearing rates were also similar across the low and high speed zones. While the percentage of cyclists with reported head injuries was a little less in the lower speed zones, the pattern was reversed for facial injuries. Therefore it appears that the incidence of the types of injuries that can be reduced by helmet wearing is similar across speed zones.

Table 30. Numbers and percentages of head and face injuries and helmet wearing rates in Police-reported bicycle crashes according to speed zone. 1993-2008.

	Speed zone ≤40		Speed zone >40	
Reported injury	Count	%	Count	%
Head	23	5.4	1164	8.7
Face	48	11.2	1326	9.9
Head and/or Face	68	15.9	2391	17.9
Helmet worn	311	72.8	9771	73.1

Based on current helmet wearing rates of 73% in both speed zones and the 70% reduction in head injuries concluded by the Cochrane Review (Thompson et al., 2009), the proportion of on-road head injuries sustained now compared to the situation if no adult riders wore helmets can be estimated as follows:

Proportion of head injuries cf no wearing

= proportion worn x head injuries despite wearing + proportion not worn x head injuries if not worn

= .73 x (1 - .7) + .27 x 1

= 0.49

Thus, if the helmet wearing rate in crashes in speed limits of 40 km/h or less fell to zero as a result of requiring helmets only for higher speed zones, then a 51% increase in head injuries in the lower speed zones would be expected. Let us assume that the wider application of 40 km/h speed zones results in 5% of Police-reported cyclist crashes occurring in these lower speed zones. This would correspond to an overall 3% increase in head injuries to all cyclists injured in on-road crashes.

Similarly, if the helmet wearing rate in crashes in speed limits of 40 km/h or less fell to half of its current rate (i.e. to 37%) as a result of requiring helmets only for higher speed zones, the proportion of head injuries (where 1 is zero wearing) would increase to 0.74. If 5% of Police-reported cyclist crashes occurring in these lower speed zones, this would correspond to an overall 1% increase in head injuries to all cyclists injured in on-road crashes.

As noted in Section 7.1, the helmet wearing rate across different speed zones could fall as a result of changing from universal to segmented legislation. If, for example, the helmet wearing rate in 50 and 60 km/h zones fell from 73% to 58%, then a 10% increase in head injuries in 50 and 60 km/h zones would be expected. Given that 50 and 60 km/h zones together comprise 90% of cyclist Police-reported crashes (see Table 6), this would correspond to an overall 9% increase in head injuries to all cyclists injured in on-road crashes.

The above analyses assume that there is no increase in the number of adult cyclist crashes on road associated with any increase in cycling accompanying the removal of the universal legislation.

7.3.2.2 Effects on injuries in off-road crashes

The hospital data show that approximately half of the cyclist hospitalisations result from traffic injuries (off-road) and half from non-traffic injuries (off-road). The AIHW reports (Henley & Harrison, 2009; Berry & Harrison, 2008) show that head injuries are the principal diagnosis for 24.6% of cyclists admitted to hospital for traffic-related injuries, but do not provide the equivalent figure for non-traffic injuries (see Table 28).

Given the absence of data on the percentage of cyclists admitted to hospital from off-road crashes who have head injuries, the approach taken here is to assume that the pattern and severity of injuries from off-road crashes is similar to that in Police-reported on-road crashes that do not involve a motor vehicle (e.g. single bicycle, multiple bicycle and bicycle-pedestrian crashes). Crashes of these types are quite plausible on bicycle paths, footpaths, and other off-road locations.

Table 31 summarises the numbers and percentages of cyclists with reported head and face injuries and helmet wearing rates in non-motor-vehicle Police-reported bicycle crashes (NMVBCs) and motor vehicle bicycle crashes (MVBCs). Helmet wearing rates were similar across the two types of crashes. The greater overall incidence of head injury in NMVBCs than MVBCs (16.7% versus 7.8%) may partially reflect greater under-reporting of NMVBCs at lower severity levels (in addition to overall under-reporting of NMVBCs at all severity levels). For example, the percentages of MVBCs that were of the lower severity levels (medically treated and minor injury) were higher than for NMVBCs (67.3% versus 59.3%). For this reason, it is necessary to compare NMVBCs and MVBCs of the same level of severity only.

Table 31. Numbers and percentages of head and face injuries and helmet wearing rates in Police-reported non-motor vehicle and motor vehicle-involved bicycle crashes. 1993-2008.

Reported injury	Non-motor vehicle involved		Motor vehicle involved	
	Count	%	Count	%
Head	176	16.7	990	7.8
Face	189	18.0	1174	9.3
Head and/or Face	354	33.7	2076	16.5
Helmet worn	763	72.6	9221	73.1

Table 32 shows that the number of NMVBCs was too small for meaningful comparisons at the fatality and minor injury severity levels. For hospitalisation and medical treatment crashes, the percentage of cyclists that were reported as having head injuries was generally about double for NMVBCs at each level of severity. This finding is somewhat surprising and may reflect the greater likelihood of limb injury or torso injury when a motor vehicle is involved in the collision.

Given the similarity between the 29% of cyclists in hospitalisation NMVBCs in the Police-reported crashes and the 24.6% of cyclists in traffic-related cyclist hospitalisations reported as having head injuries in the AIHW data, it is proposed to assume that the 24.6% value applies to both on- and off-road hospitalisations.

There is no evidence on whether helmet wearing rates differ between on- and off-road crashes. For this reason, the estimates below assume that they are the same and use 73%, consistent with the wearing rates in the police-reported crashes shown in Table 31.

Table 32. Numbers and percentages of head and face injuries in Police-reported non-motor vehicle and motor vehicle-involved bicycle crashes according to crash severity, 1993-2008.

	Non-motor vehicle involved		Motor vehicle involved	
	Count	%	Count	%
Fatality				
Head	10	58.8	55	40.7
Face	0	0.0	0	0.0
Head and/or Face	10	58.8	55	40.7
Hospitalisation				
Head	119	29.0	628	16.2
Face	91	22.2	456	11.8
Head and/or Face	202	49.3	1022	26.4
Medical treatment				
Head	45	11.1	260	4.7
Face	81	19.9	580	10.5
Head and/or Face	123	30.2	821	14.9
Minor injury				
Head	2	0.9	47	1.5
Face	17	7.8	138	4.5
Head and/or Face	19	8.8	178	5.7

Based on current helmet wearing rates of 73% for adult cyclists and the 70% reduction in head injuries concluded by the Cochrane Review (Thompson et al., 2009), the proportion of off-road head injuries sustained now compared to the situation if no off-road riders wore helmets is 0.49, because it is based on the same proportions as in the Police-reported on-road crashes. Thus, if the helmet wearing rate off-road fell to zero as a result of requiring helmets only for on-road use in speed limits of greater than 40 km/h, then a 51% increase in off-road head injuries would be expected. Given that adults off-road riding comprises 50% of cyclists hospitalised, this would correspond to an overall 26% increase in head injuries to all cyclists hospitalised following off-road crashes.

Similarly, if the helmet wearing rate off-road fell to half of its current rate (i.e. to 37%) as a result of requiring helmets only for on-road use where the speed limit was greater than 40 km/h, the proportion of head injuries (where 1 is zero wearing) would increase to 0.74. Given that 50% of cyclists hospitalised are in off-road crashes, this would correspond to an overall 13% increase in head injuries to all cyclists hospitalised following off-road crashes.

The above analyses assume that there is no increase in the number of off-road adult cyclist hospitalisations associated with any increase in cycling accompanying the removal of the universal legislation.

7.3.3 Mandatory helmet wearing when riding on roads but not on bicycle paths or footpaths or off-road

7.3.3.1 Effects on injuries in on-road crashes

The only effect on on-road crashes would be the indirect effect. If the indirect effect of not requiring a helmet to be worn off-road led to a reduction in helmet wearing rates on-road from 73% to 58%, then this would correspond to a 10% increase in head injuries in on-road crashes.

7.3.3.2 Effects on injuries in off-road crashes

The effect on head injuries in off-road crashes would be the same as calculated in Section 7.3.2 for requiring helmet use only for on-road riding where the speed limit was greater than 40 km/h. A reduction in off-road helmet wearing rates to zero was predicted to lead to a 51% increase in off-road head injuries, corresponding to an overall 26% increase in head injuries to all cyclists hospitalised following off-road crashes. Similarly, if the helmet wearing rate off-road fell to half of its current rate (i.e. to 37%) as a result of requiring helmets only for on-road use where the speed limit was greater than 40 km/h, the proportion of head injuries (where 1 is zero wearing) would increase to 0.74. Given that 50% of cyclists hospitalised are in off-road crashes, this would correspond to an overall 13% increase in head injuries to all cyclists hospitalised following off-road crashes.

The above analyses assume that there is no increase in the number of off-road adult cyclist hospitalisations associated with any increase in cycling accompanying the removal of the universal legislation.

7.3.4 Summary of potential effects of different segmentation approaches

Table 33 summarises the direct and indirect effects on on-road and off-road crashes of each of the segmentation approaches discussed earlier. The total estimated effect has not yet been calculated, because it requires consideration of the likely levels of under-reporting and consideration of what levels of severity of head injury (and of crashes in general) should be incorporated.

Table 33. Summary of potential effects of different segmentation approaches in Queensland.

Approach	On road crashes	Off road crashes	All bicycle crashes
Mandatory for under 18 only			
Direct effect			
Halve wearing rate	28% inc in HI adults 18% inc in HI all cyclists	28% inc in HI adults 10% inc in HI all cyclists	28% inc in HI adults 14% inc in HI all cyclists
Zero wearing rate	56% inc in HI adults 36% inc in HI all cyclists	56% inc in HI adults 20% inc in HI all cyclists	56% inc in HI adults 28% inc in HI all cyclists
Indirect effect			
Drop in child wearing rate from 65% to 50%	10% inc in HI children 3% inc in HI all cyclists	10% inc in HI children 6% inc in HI all cyclists	10% inc in HI children 4% inc in HI all cyclists
Mandatory on roads with speed limit greater than 40 km/h			
Direct effect			
Halve wearing rate	26% inc in HI 40 km/h zones 1% inc in HI all cyclists	26% inc in HI	13% inc in HI all cyclists
Zero wearing rate	51% inc in HI 40 km/h zones 3% inc in HI all cyclists	51% inc in HI	27% inc in HI all cyclists
Indirect effect			
Drop in wearing rate on 50 and 60 km/h roads from 73% to 58%	10% inc in HI 50 and 60 km/h zone 9% inc in HI all cyclists		4% inc in HI all cyclists
Mandatory on roads but not off-road			
Direct effect			
Halve wearing rate		26% inc in HI	13% inc in HI all cyclists
Zero wearing rate		51% inc in HI	26% inc in HI all cyclist
Indirect effect			
Drop in wearing rate on roads from 73% to 58%	10% inc in HI		5% inc in HI all cyclists

7.4 Practical challenges in segmenting bicycle helmet legislation in Queensland

A number of practical challenges associated with location-based bicycle helmet legislation are described in Section 7.1.

If bicycle helmet wearing was only mandatory for children, enforcement would be difficult, and police might be unwilling to stop unhelmeted riders to find out their age. Would riders have to carry proof of age? Police are unwilling to follow-up drivers who are not carrying their licence, so it would not seem likely that there could be an effective enforcing of helmet wearing among adolescents. Unfortunately, this is the group for which wearing rates are already lower than for adults, and where risk taking may be contributing to cyclist injury.

Segmenting of helmet legislation on the basis of on- or off-road legislation may pose difficulties for riders to understand what is meant by road and off-road. This has already proven difficult for motorcycles and off-road driving.

Another practical difficulty for legislators in segmenting bicycle helmet legislation is that of "legislative creep". It may be difficult to maintaining a segmented approach against logical arguments that it should be all or none. In addition, other groups may see the opportunity to press for segmented legislation. While it is hoped that this would not occur for motorcycle riders, it may be possible that moped riders would claim that they are similar to bicycle riders (not requiring licensing) and may also press for segmented helmet legislation to apply to them.

7.6 Conclusions regarding segmenting bicycle helmet legislation in Queensland

Moving from universal helmet wearing legislation to a segmented approach will have a direct effect on those who no longer are required to wear a helmet and an indirect effect in reducing helmet wearing rates among those who are still required to wear a helmet.

There are no exact methods to generate accurate numerical predictions of what the effects of changing to a segmented approach would be. In this section we have used a combination of available data on police-reported on-road bicycle crashes and hospitalisation data for on- and off-road crashes to provide indications of the possible effects on head injuries to cyclists.

All of the proposed approaches to segmenting bicycle helmet legislation are predicted to result in substantial increases in the percentage of riders in crashes who sustain head injuries. The values that follow are based on a halving of wearing rates if it was no longer mandatory. If helmet wearing was required only for riders aged under 18, then this would result in an increase of about 14% in the number of cyclists sustaining head injuries in on-road crashes (according to Police-reported data) or an increase of about 20% in both on- and off-road cyclist head injuries, according to hospital data. Any change in helmet wearing legislation that no longer required helmet wearing when not on public roads is predicted to result in an increase in head injuries of about 26% in off-road crashes, and an indirect increase in on-road cyclist head injuries of about 10%.

8. CONCLUSIONS AND RECOMMENDATIONS

Current bicycle helmet wearing rates are halving the number of head injuries experienced by Queensland cyclists. This is consistent with published evidence that mandatory bicycle helmet wearing legislation has prevented injuries and deaths from head injuries.

It is reasonably clear that it discouraged people from cycling twenty years ago when it was first introduced. Having been in place for that length of time in Queensland and throughout most of Australia, there is little evidence that it continues to discourage cycling. There is little evidence that there is a large body of people who would take up cycling if the legislation was changed.

Any move from universal helmet wearing legislation to a segmented approach would have a direct effect on those who no longer are required to wear a helmet and an indirect effect in reducing helmet wearing rates among those who are still required to wear a helmet. While there are no exact methods to generate accurate numerical predictions of what the effects of changing to a segmented approach would be, segmenting bicycle helmet legislation according to age or riding location is predicted to result in substantial increases in the percentage of riders in crashes who sustain head injuries.

Cycling does have significant health benefits and therefore should be encouraged in ways that reduce the risk of the most serious of injuries. Head injuries not only have the potential for death but that they are among the most disabling of non-fatal injuries (in some ways more than spinal injuries). Infrastructure and speed management approaches to improving the safety of cycling should be undertaken as part of a Safe System approach, but protection of the individual by simple and cost-effective methods such as bicycle helmets should also be part of an overall package of measures.

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