Cyclist safety: an investigation of how cyclists and drivers interact on the roads

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Thesis summary

Cyclists are vulnerable road users and the most severe injury outcomes for on-road cyclists are from collisions involving a motor vehicle. Research undertaken in this thesis aimed to identify contributing factors in unsafe cyclist-driver events to inform efforts to reduce the incidence of cyclist-driver crashes and cyclist injury severity outcomes. The research was conducted in three stages, primarily in Melbourne, Victoria, Australia and is presented as a thesis by publication.

The Safe System Framework was used as the theoretical model for the research and the research stages included i) an observational study using a covertly positioned video camera at signalised intersections across metropolitan Melbourne; ii) a naturalistic cycling study using a compact video camera attached to commuter cyclists' helmets which recorded their trips to and from work; and, iii) a national online survey of drivers and cyclists of their cycling-related behaviours, knowledge and attitudes.

The role of driver behaviour in cyclist-driver crashes and near-crash events was identified and was the most significant finding of this doctoral research. In-depth analysis of near-collision events revealed that drivers' behaviour immediately prior to an event contributed to the majority of unsafe interactions between cyclists and drivers. The most frequent driver behaviour associated with near-collision events was turning left across a cyclists' path. Three important components of this behaviour were: indicating (signalling) before turning, driver head checks before turning left and clearance distance when overtaking cyclists.

These three behavioural components were investigated further, with a particular focus on the influence of cycling-related knowledge and attitudes. Findings supported the concept of safety in numbers which proposes a positive association between cycling participation and cyclist safety. A significant finding was that drivers who were also cyclists (driver-cyclists) were more likely than drivers who were not cyclists to report safe driving behaviours. Driver-cyclists also reported more positive attitudes towards cyclists and good knowledge of road rules for cycling facilities.

Cyclist behaviour had also been identified as a potential crash risk factor, particularly red light running behaviour. Encouragingly, however, only a small proportion of observed cyclist infringed and predictive factors included direction of

travel (left turn) and gender (male). The presence of other road users (cross traffic and in the same direction) had a deterrent effect.

Last, the presence of cycling facilities was associated with cyclist-driver interactions. Cyclist and driver behaviour at two cycling facilities at intersections (bike boxes and continuous bike lane) was measured. Despite the high level of knowledge of bike boxes, many drivers were non-compliant at this type of facility. In contrast, both cyclists and drivers were more likely to be compliant at the facility that provided a continuous parallel bike lane compared with the bike box facility.

Findings of this research provide new insights into the influence of behavioural factors and presence of cycling facilities on cyclist safety. Greater cyclist-related driver education and training are essential to improve cyclist safety. It is anticipated that the findings from this research will inform programs and initiatives that will improve the safety of on-road cyclists.

General Declaration

In accordance with Monash University Doctorate Regulation 17/ Doctor of Philosophy regulations the following declarations are made:

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes four original papers published in peer reviewed journals and one unpublished publication. The core theme of the thesis is cyclist safety. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the candidate, working within the Monash University Accident Research Centre under the supervision of Dr Judith Charlton and Dr Jennifer Oxley.

The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research. In the case of Chapters 5, 6, 7, 8 and 9 my contribution to the work involved the following:

Thesis chapter	Publication title	Publication status
5	Riding through red lights: The rate, characteristics and risk factors for non-compliant urban commuter cyclists	Published
6	Painting a designated space: Cyclist and driver compliance at cycling infrastructure at intersections	Published
7	The application of a naturalistic driving method to investigate on-road cyclist behaviour: A feasibility study	Published
8	Naturalistic cycling study: identifying risk factors for on-road commuter cyclists	Published
9	Cyclist safety and the role of driver behaviour, knowledge and attitudes	Submitted

The nature and extent of candidate's contribution are as stated in the Author's declaration page included in each chapter. The sections of submitted or published papers have been renumbered in order to generate a consistent presentation within the thesis.

Signed: [redacted]..

Date: 20 May 2011

Acknowledgements

It is with great joy and even greater relief that I submit this thesis for examination. This thesis was a collaborative effort that I was only able to complete with the help, guidance and support of many people, some of whom I'd like to thank here.

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Finally, and most importantly, thank you to my husband, Derek Chong. Thank you for your encouragement, continuous support, countless (endless?) hours of patient listening and indulgence. Now we can go on a holiday!

Chapter 1
Introduction

In Australia, the popularity of cycling has increased over recent years. From 2001 to 2009, there was a 32 per cent increase in the number of people cycling (Department of Communications Information Technology and the Arts, 2009). While there are numerous benefits to regular bicycle riding, cyclists are physically vulnerable road users (Richter, Otte, Haasper, Knobloch, Probst et al., 2007), especially those cyclists who choose to ride on the road. Since 2001, in Australia, there has been a concurrent increase in the number of people cycling and the number of cyclists seriously injured (Henley & Harrison, 2009; Department of Communications Information Technology and the Arts, 2010). Collisions with a motor vehicle result in the most severe injury outcomes for cyclists (Bostrom & Nilsson, 2001; Haileyesus, Annest & Dellinger, 2007; Chong, Poulos, Olivier, Watson & Grzebieta, 2010) and a cyclist's risk of serious injury is 3.6 times greater in a collision with a vehicle compared with all other non-vehicle cyclist crash types (Rivara, Thompson & Thompson, 1997).

The overall aim of this doctoral research was to identify characteristics of the road users and road system that contribute to cyclist crash risk. It was anticipated that insights gained would contribute to efforts to improve safety for on-road cyclists and reduce cyclist-driver collisions. The research was primarily conducted in Melbourne, the capital city of the south-eastern state of Victoria, Australia, where there has been a significant increase in the number of people cycling.

To address the issue of cyclist safety, it was important to first review the context in which cycling occurs. In particular, in order to understand cyclist crash rates, it is critical to know cyclists' exposure or the number of people cycling in Australia. Australian cycling participation data was reviewed with some comparisons made to international cycling participation levels. The safety in numbers concept was also discussed. Next, the cyclist crash data was reviewed to understand the nature and extent of cyclist road trauma in Australia; this section also includes some international comparisons, a discussion of data limitations and the cost of cyclist crashes. This is followed by an overview of cyclist safety in Australia, including bicycle helmet use legislation and government cycling policy. The chapter concludes with a description of the thesis structure.

1.1 Cycling participation

An accurate picture of cycling participation is necessary to ensure that trends can be monitored to inform policy, allocation of resources and for use as denominator data in the calculation of cyclist risk. In this section, the Australian and some international cycling participation data and the safety in numbers concept are discussed.

1.1.1 Cycling participation – Australia

In Australia, a range of government departments and community organisations collect cycling participation data. However, currently there is no comprehensive, co-ordinated national record of the number of people cycling, nor is there any available detailed data on trip frequency, trip purpose, distance travelled, time spent riding or cyclists' characteristics (Australian Transport Safety Bureau, 2006; Garrard, 2009; Sikic, Mikocka-Walus, Gabbe, McDermott & Cameron, 2009). Nevertheless, all available indicators suggest that the number of people cycling in Australia is increasing.

Since 2001, the Australian federal government has conducted an annual, national telephone survey, the Exercise, Recreation and Sport Survey (ERASS). The ERASS provides self-reported data on physical activity participation by Australians aged 15 years and over (Department of Communications Information Technology and the Arts, 2010). Consistently, for each year of the study (from 2001 to 2009), cycling was ranked the fourth highest activity in terms of total participation (at least once in the last 12 months), after walking, aerobics/fitness and swimming.

This survey also reported that in 2009, over 1.9 million Australians aged over 15 years cycled at least once during the year. Over the entire period from 2001 to 2009, there was a 32 per cent increase in the total number of people cycling (see Figure 1-1) (Department of Communications Information Technology and the Arts, 2010).

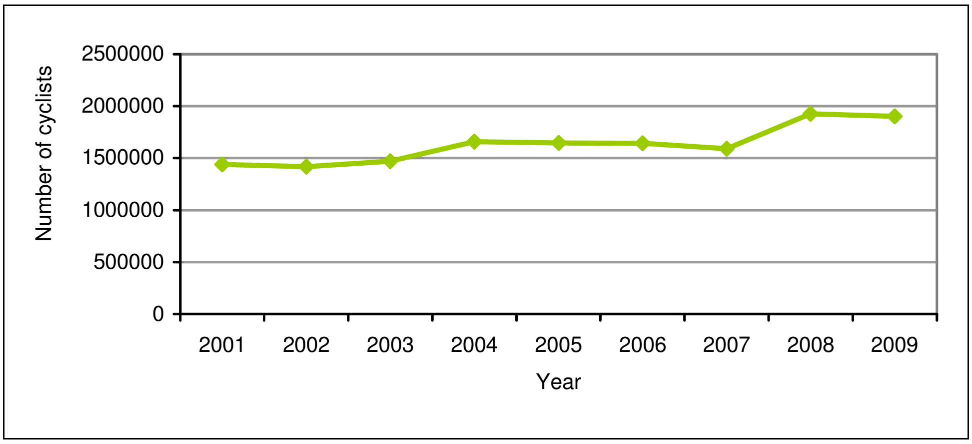

Figure 1-1 Cycling participation in Australia (over 15 years of age), 2001-2009 (Department of Communications Information Technology and the Arts, 2001-2009)

In 2010, 23.5 per cent of people who cycled reported regular participation (defined as cyclist 3 or more times per week). Nationally, regular cyclists were more likely to be male (65.1%) and aged 35-44 years (29.5%) (Department of Communications Information Technology and the Arts, 2010).

The ERASS provides an overview of cycling participation data; however, to understand cycling participation for road safety purposes, more detailed data is required. In recent years, efforts to generate this type of data have gained momentum.

Since 2007, in Melbourne, Victoria, a visual count of cyclists has been conducted at key intersections and along major commuter routes. Called 'Super Tuesday', the count is conducted during morning peak travel times (7-9am) on a Tuesday in March. The count is organised by Bicycle Victoria, a not-for-profit cycling advocacy group based in Melbourne and volunteers conduct the counts manually. The number of observation sites has expanded each year and in 2010, the count included all states and territories in Australia (excluding the Northern Territory) and one site in New Zealand.

Observations were mainly conducted in capital cities, with limited observations in regional areas of Victoria and Queensland (Bicycle Network, 2010).

The Super Tuesday counts for Melbourne from 2009 to 2010 reported a 20 per cent increase in the number of cyclists, with even greater increases reported at specific sites. For example, the intersection of Flinders Street and Swanston Street in the Melbourne central business district (CBD) increased by 29 per cent and Napier Street, Fitzroy, an inner city suburb of Melbourne increased by 50 per cent. The Napier Street increase was attributed to the installation of bike-priority signals in 2009 (Bicycle Network, 2010).

In Australia, the Super Tuesday count is the most comprehensive observational study undertaken to date, providing data on cyclist numbers during morning hours. However, there are two major methodological limitations to the count. First, sampling is conducted on only one day and this has implications for the representativeness of the count. For some cyclists riding to work is a daily activity; however for many people, riding to work is a less frequent activity and the decision to cycle is affected by numerous personal and professional factors. In addition, by sampling on only one day, the data is susceptible to variation due to weather, especially since inclement weather can be a deterrent for some cyclists (Nankervis, 1999). Second, manual counting protocol is subject to human error due to observation fatigue especially in complex environments, such as a busy intersection at peak travel times (Arnberger, Haider & Brandenberg, 2005). Despite these limitations, the Super Tuesday count is the most comprehensive data source currently available in Australia for morning cyclists.

There are other reports that confirm that cycling mode sharing in Australia is increasing (City of Melbourne, 2008). However, there is a perception amongst the international road safety community that this is not the case and only a very small proportion (1%) of all trips made in Australia are by bicycle (Pucher & Buehler, 2008b). This estimate is generated by the Australian Census of Population and Housing, conducted by the Australian Bureau of Statistics. The census is a cross-sectional survey of the entire Australian population and generates a snapshot of a range of topics including household population, work patterns, income, education and transportation modes. However, there are a number of inherent limitations in using this data to monitor cycling mode share. The census is conducted on one day and therefore is subject to similar limitations as the Super Tuesday count. The information on cycling activity is generated by one question that asks how each person travelled to work on that day. There is no opportunity for respondents to provide information on non-commuting cycling activity, therefore the data excludes all bike trips made for other purposes other than commuting such as utilitarian, fitness or leisure or by people who did not travel to work on that day. Further, the census is conducted in August which is the last month of winter in the southern hemisphere. August is one of the coldest months of the year and one with the fewest number of daylight hours. Cycling participation is therefore likely to be lower during August than in other months.

Despite these limitations, the census data is the only national data source that records all modes of travel, albeit only for the purpose of commuting to work. In the absence of a more comprehensive cyclist-inclusive dataset, Australian census data have been widely used in published reports. For example, census data were used in the Victorian government's roads and licensing authority (VicRoads) report on Cycling to Work in Melbourne 1976-2001 and reported that the proportion of trips to work by bicycle increased from 1976 (1.0%) to 2001 (1.18%) (VicRoads, 2004). In Sydney, Telfer and Rissel (2003) also used census data to compare residents riding patterns in 1996 with 2001. While there was a 53 per cent increase in the number of people cycling, the total bicycle mode share was still only 1.21 per cent of all commuter travel modes in 2001 (Telfer & Rissel, 2003).

Numerous smaller scale location-specific surveys offer a partial view of the cycling activity within Australia. Examples of such surveys in Victoria include: the Victorian Activity and Travel Survey (VATS) (1994-1999), the Victorian Integrated Survey of Travel and Activity (VISTA) (May 2007 to June 2008) (Garrard, Greaves & Ellison, 2010). However, these surveys have been conducted in relative isolation and cannot be used to determine cycling participation trends. Additionally, bicycle sales provide a proxy indicator of the increasing popularity of cycling. In Australia, in 1998, approximately 650,000 bicycles were sold. Since 2002, bicycle sales have exceeded 1 million per year. Interestingly, since 2001, bicycles have outsold all motor vehicles types combined (Cycling Promotion Fund, 2009). The motivations for increased bicycle sales are not clear but may be attributed to a range of inter-related factors including the rise in popularity of cycling for health, fitness and recreational purposes. Increasing vehicle fuel prices or environmental concerns related to car travel may also have contributed to the rise in bicycle sales. Although bicycle sales provide a useful economic indicator, they cannot be used as an indicator of participation. Multiple purchases by an individual is a potential confounder when estimating the number of people cycling

(Cupples & Ridley, 2008) and therefore it is not possible to extrapolate cycling participation data from bicycle sales alone.

While the available data sources provide some information on cycling activity, the data cannot be linked and significant gaps remain. More detailed cycling participation data in Australia is needed in order to ascertain accurate exposure data (Chapman, 1973; Sikic et al., 2009). A co-ordinated and in-depth approach to cycling participation data collection is required to provide a more comprehensive understanding of cycling rates and patterns in Australia (City of Melbourne, 2004; Bonham, Cathcart, Petkov & Lumb, 2006).

In countries where cycling participation is higher, such as the Netherlands, Denmark and Sweden, extensive, continuous, detailed surveys have been conducted to ascertain the number of people cycling. These data allow for more accurate calculations of cycling as a transport mode and of cyclist crash rates. For example, the Dutch Mobility Survey (National Travel Survey or MON), has been conducted continuously since the 1980s and uses a travel diary to collect detailed data about individual trips (SWOV Institute for Road Safety Research, 2009). International cycling participation rates are reviewed in the next section.

1.1.2 Cycling participation – international

Cycling participation rates vary considerably worldwide and a range of factors including social, economic, infrastructure and cultural, contribute to these international differences. International bicycle share of trips, including Australia, are included in Figure 1-2.

In Europe, countries with the highest proportion of trips made by bicycles are the Netherlands (27%), followed by Denmark (18%), Finland (11%), Sweden (10%) and Germany (10%) (Jacobsen, 2003; Pucher & Buehler, 2008b). To achieve such high cycling rates, support for cycling has been broad and multi-faceted. Initiatives have included provision of physical facilities, traffic calming measures in residential areas, adequate end-of-trip facilities and integration with public transport (Jacobsen, 2003; Pucher & Buehler, 2008b). In these countries, there are many examples of bicycle-inclusive urban planning and well connected routes that deliberately provide a more direct route by bicycle than vehicle to encourage cycling. Deterrents that actively discourage motor vehicle use in urban areas include: taxes, restrictions on car ownership, use and parking (Jacobsen, 2003; Pucher & Buehler, 2008b). Significant funding supports many of the initiatives, for example, the German government contributed €1.1 billion to double bikeways along federal highways from 1980-2000 and an additional €100 million per year to expand cycling infrastructure (Pucher & Buehler, 2008b).

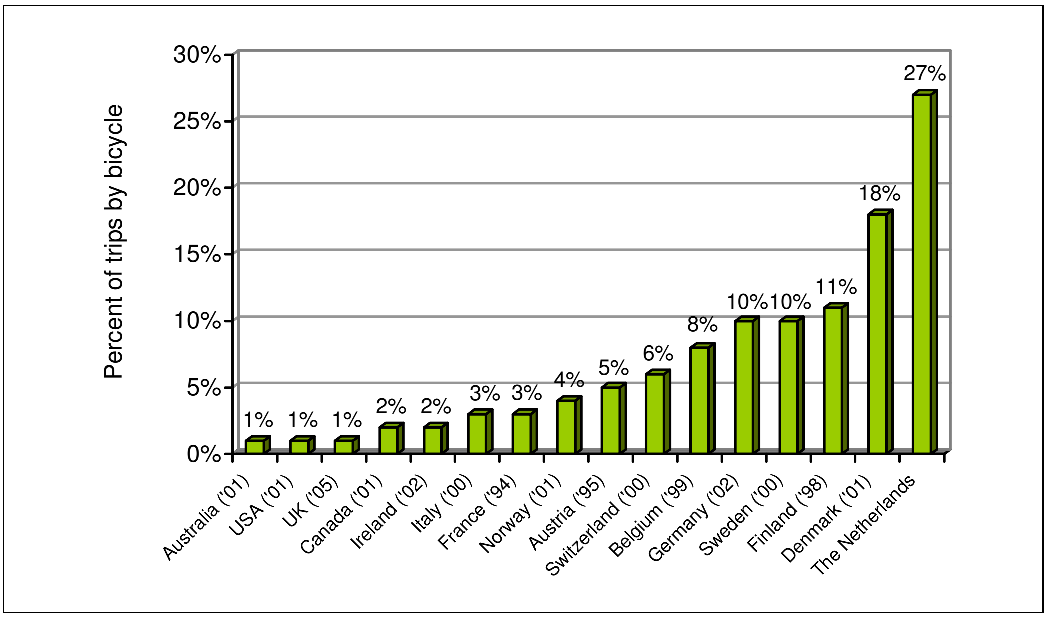

Figure 1-2 Bicycle share of trips in Europe, North America and Australia (percent of total trips by bicycle) (Pucher & Buehler, 2008b)

Even in countries with low cycling participation, such as the United States of America (US), increased and improved cycling facilities in some cities has been associated with an increase in the number of people riding bikes (Dill & Carr, 2003; Pucher & Buehler, 2008b). Studies in Portland Oregon, reported that access to a bicycle and highly connected bike lanes/paths were associated with more cycling (Dill & Voros, 2007) and provision of cyclist-inclusive infrastructure and urban planning was important to increase regular adult cycling (Dill, 2009). Cycling infrastructure may also be a key factor in cyclist safety and its role was explored in this doctoral research, as described in Chapters 6 and 9.

Legislation in some European countries protects vulnerable road users and is strictly enforced (Pucher & Dijkstra, 2003). In the Netherlands, default responsibility holds drivers completely responsible for damages in a collision with a cyclist aged 14 years or younger (Skelly, 1995; Petty, 1998). In Germany, since 2002, children under 7 years are not held responsible for damages causes by negligence in road traffic. In France and Germany, the 'keeper of the vehicle' is responsible for losses sustained in cyclist-driver crashes. However, in Germany, a caveat exists, specifying that reckless behaviour of a cyclist in traffic will undermine their legal position and mitigate driver responsibility (Fedtke, 2003). In Australia, there is no default driver responsibility law for cyclist-driver crashes involving cyclists of any age so that crash responsibility may be assigned to either driver, cyclist or both.

While cycling participation is increasing in European countries, the opposite trend is occurring in some Asian countries where traditionally cycling had a central role in daily lives. Rapid economic development, associated motorisation and increasing availability of inexpensive motor vehicles have contributed to a decrease in bicycle use. In 1996, major cities in China had the highest bicycle mode share in the world: bike trips accounted for over 90 per cent of total trips (Hook & Replogle, 1996). By 2006, this had dropped to 40 per cent (Yan-Hong, Rahim, Wei, Gui-Xiang, Yan et al., 2006). Similar declines in bike mode share have been reported in Vietnam and Cambodia (Bell & Kuranami, 1994).

In recent decades, one of the most dramatic city transformations in the use and inclusion of bicycles has been in South America, in Bogotá, the capital city of Columbia. Support for cycling in this city came from a series of political leaders that included Enrique Peñalosa and Antanas Mockus who worked to create a human friendly environment by reclaiming public spaces, promoting non-motorised transport and restricting vehicle use. Public reclaiming of the streets was bolstered by the *ciclovía*. Spanish for bike path, the term is used to refer to the temporary closing of city streets to motorised vehicles to allow all non-motorised forms of transport, cyclists, pedestrians, joggers and skaters to use 120km of roadway car-free. The first *ciclovía* was held in 1982 and it is now a weekly event, with the roads closed each Sunday and public holidays (Wright & Montezuma, 2004).

While global rates of cycling participation vary considerably, as cycling participation increases in European countries, a relationship has been identified between high cycling participation and low rates of cyclist fatality and serious injury crashes. This inverse relationship is based on Smeed's law and recently became known as the *safety in numbers effect* (Jacobsen, 2003). The link between cyclist volumes and crash rates is discussed in the next section.

1.1.3 Safety in numbers

In European countries where cycling participation is high, an association has been demonstrated between the high cycling participation and low crash risk, (Jacobsen, 2003; Pucher & Buehler, 2008b). The safety in numbers effect is explained thus: As more people cycle:

- drivers will have an increased expectation of cyclists on the road and look out for them
- drivers will be more likely to ride a bike and understand how to safely interact with cyclists on the road
- non-cycling drivers will be more likely to know someone who rides a bike, a friend, family member or colleague, so cyclists are less likely to be considered a marginalised group (Jacobsen, 2003; Crundall, Bibby, Clarke, Ward & Bartle, 2008)

Notwithstanding the small reported proportions of cyclists in Australia, the safety in numbers concept was investigated in an Australian study in the South Australian capital, Adelaide (Bonham et al., 2006). Crash rates were computed using police crash reports and cyclist volumes from the 1999 Metropolitan Adelaide Household Travel Survey and estimates from intersection and cordon counts at 17 entry points to the Adelaide central business district (CBD). The authors reported that as the number of cyclists increased, so too did the absolute number of cyclist crashes, however regression analysis of percentage of cyclists who crashed by cyclist trips on road showed that the likelihood of an individual cyclist being involved in a crash declined (Bonham et al., 2006).

Bonham and colleagues (2006) proposed that the most important factor for cyclist safety was the frequency of cyclist-driver encounters and this was more important than the drivers' experience of being a cyclist themselves. The authors concluded that while there may be benefits for cyclists during high cyclist travel times, this may not generalise to other times (Bonham et al., 2006). Similar findings were reported by Maycock et al, based on research in the UK and suggest that when drivers have infrequent encounters with a road user group, such as cyclists, they have less appreciation of that groups' behaviour and safety needs (Maycock, Brocklebank & Hall, 2003).

More recently, Turner, Wood, Luo, Singh and Allatt (2010) used mathematical crash prediction models to investigate the relationship between traffic flow and cyclist-driver crashes in New Zealand. They reported risk reductions when cyclist volumes reached 100 cyclists per day per approach at traffic signals and 150 cyclists per day on midblock sections. As the traffic volume increased, the total number of cyclist crashes increased but the rate of crashes decreased (Turner, Wood, Luo, Singh & Allatt, 2010).

While the safety in numbers concept has been put forward in an attempt to explain trends in crash data for vulnerable road user groups, it is acknowledged that this association does not imply causation (Pucher & Buehler, 2008b; Turner et al., 2010). In a pedestrian safety review, Bhatia and Wier (2011) identified potential environmental confounders as being likely to increase safety, including lower traffic speed, greater buffers between drivers and pedestrians and reduced traffic volume. Rather than the concept of increasing pedestrian numbers creating a safer environment, the authors argued that the converse is true: that is, a safer environment encourages more people to walk. Bhatia and Weir noted that the safety benefits associated with increased volume of pedestrians may also lead to stronger political support and more consistent enforcement of dangerous driver behaviours. Importantly, the authors concluded that to assume a causal link between increased numbers and improved pedestrian safety is premature (Bhatia & Wier, 2011).

It is difficult to determine if a safety in numbers effect has been achieved in Australia, as the lack of exposure data precludes the derivation of meaningful crash rates. Based on the indicative data available, the reported increase in the number of people cycling has not been accompanied by a concurrent drop in cycling crashes. Indeed, the crash statistics show an increase in the number of cyclist serious injuries. In the next section, cyclist crash statistics in Australia are reviewed.

1.2 Cyclist crash statistics

Globally, in 2004, road traffic crashes were the 9th leading cause of death. The World Health Organisation estimated that by 2030, road traffic crashes will be the 5th leading cause of death (World Health Organisation, 2009). In Australia, the annual number of road user fatalities, including cyclists, has decreased over the last 30 years. However, since 2000/01, cyclist serious injury crashes have increased dramatically. In this section, the broad patterns of cyclist fatality and serious injury crashes in Australia are deconstructed and consideration is given to research methods and findings elucidating potential risk factors for cyclist crashes.

1.2.1 Cyclist fatalities

All road fatalities in Australia are reported in an annual summary by the Australian federal government (Bureau of Infrastructure Transport and Regional Economics, 2010). Cyclist fatalities from 1982 to 2009 are presented in Figure 1-3 and show a downward trend, the greatest decrease occurred in the early 1990s. Prior to 1990, the average annual number of cyclist fatalities was 87, in 1992 this dropped to 41. The reasons that may have contributed to this decrease are discussed later in this chapter in Section 1.3. The downward trend continued through the 1990s but has plateaued somewhat from 2005.

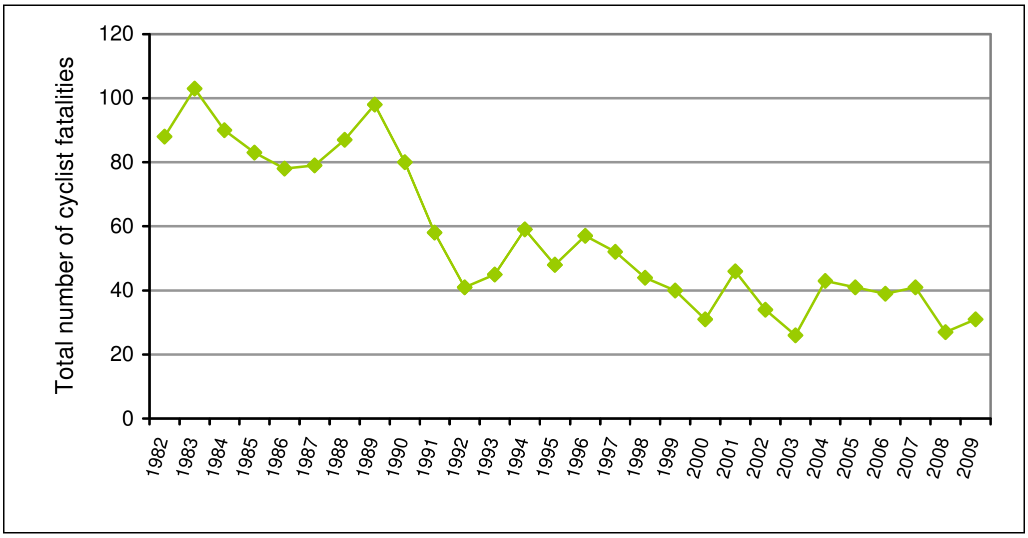

Figure 1-3 Australian cyclist fatalities 1982-2008
(Created from Bureau of Infrastructure, Transport and Regional Economics, 2010)

Cyclists represent a very small percentage of the total road toll in Australia; under 3 per cent of all fatality crashes from 2000 to 2009 (Bureau of Infrastructure Transport and Regional Economics, 2010). Yet, the risk of fatality per kilometre travelled is considerably higher for cyclists compared with drivers. This is not surprising, given that cyclists are physically unprotected road users. Garrard, Greaves and Ellison (2010) reported that in Melbourne, the relative risk of fatality per kilometre travelled for cycling compared with driving was between 5 and 19 (Garrard et al., 2010).

Fatality rates per kilometre travelled have been used to identify the safety of cyclists in Europe and the US. Figure 1-4 shows the fatality rates per 100 million kilometres cycled for 9 countries.

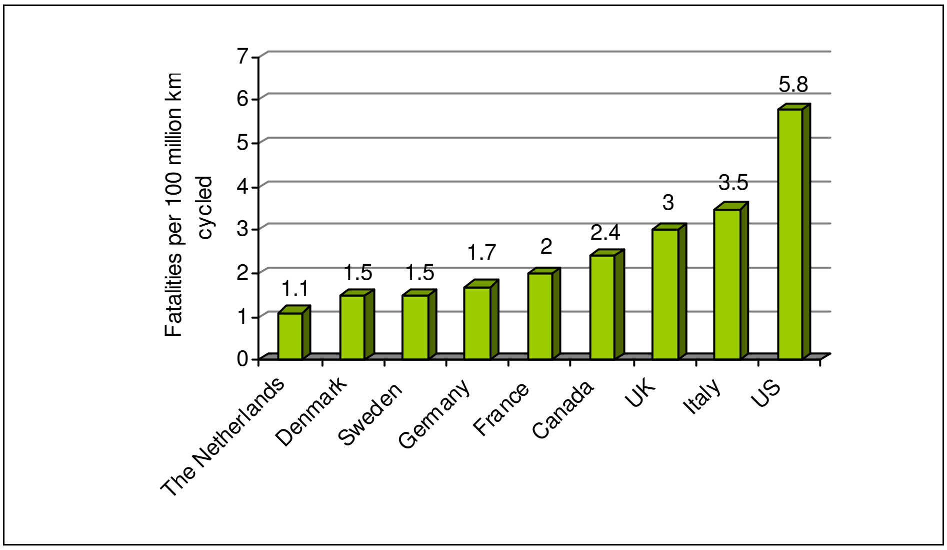

Figure 1-4 Cycling fatality rates in Europe and the US, 2002-2005 average
(Pucher & Buehler, 2008a)

The use of relative rates, such as fatalities per kilometres travelled, is essential to understanding cyclist safety. By monitoring such rate changes, the safety of cyclists can be more accurately understood in the context of changes in cycling patterns. However, as discussed in Section 1.1 cycling participation data in Australia is limited and consequently, it is not possible to determine an Australian cyclist fatality rate per kilometres travelled.

The most detailed report of cyclist fatality crashes in Australia was conducted by the Australian Transport Safety Bureau (ATSB), the federal government national transport safety investigation agency. The report entitled, *Deaths of cyclists due to road crashes* provided an analysis of police reports for 665 on-road cyclist fatalities from 1991 to 2005 and included an in-depth analysis of coronial data for 220 cyclist fatalities (Australian Transport Safety Bureau, 2006). The most common cyclist fatality crash characteristics identified in the report were:

- other road user involved: driver (86%) – of those, passenger/light commercial vehicles (74%), heavy transport vehicles (26%)

- most frequent collision type: cyclist hit from behind by a vehicle travelling in the same direction (19%)
- speed zone: 70km/h or below (58%)
- location: urban areas (69%)
- time: during daylight hours (74%)
- day of week: weekdays (75%)
- weather: fine (86%)
- cyclist killed: gender, male (85%); age, 20 years or older (67%)

The cyclist fatality crash characteristics described above (Australian Transport Safety Bureau, 2006) provided a rationale for the focus on commuter cyclists in this doctoral research. Inherently, the emphasis on commuter cyclists also directed the investigation of several crash characteristics, specifically: speed zones 70km/h or below; urban areas; during daylight hours and on weekdays. Fine weather could also be included by restricting data collection days. The full decision making process for cyclist type is described in Chapter 3. The ATSB report also identified crash contributory factors that were addressed in this doctoral research and these are discussed in Chapter 2.

Since 2005, the number of cyclist fatalities in Australia has plateaued. At first glance, this bodes well for cyclists, however, fatalities are not the only measurement of safety (Gordon, 1949). In Australia, since 2000/01, the number of cyclists who have been seriously injured has increased dramatically. Cyclist serious injury crash data are discussed in the next section.

1.2.2 Cyclist serious injuries

In Australia, from 2000/01 to 2006/07, cyclist on-road crashes resulting in serious injuries have increased by 14.6 per cent (see Figure 1-5). In 2006/07, 15 per cent of all people seriously injured in road traffic crashes in Australia were cyclists (see Figure 1-6). The most common cyclist serious injuries were to shoulder/upper limb (43.2%) and head (23.6%). The mean length of hospital stay was 2.9 days. In 2006/07, half of all cyclists seriously injured were over 18 years (50.5%) and over half of all adult cyclist crashes occurred on the road (56.1%) (Henley & Harrison, 2009).

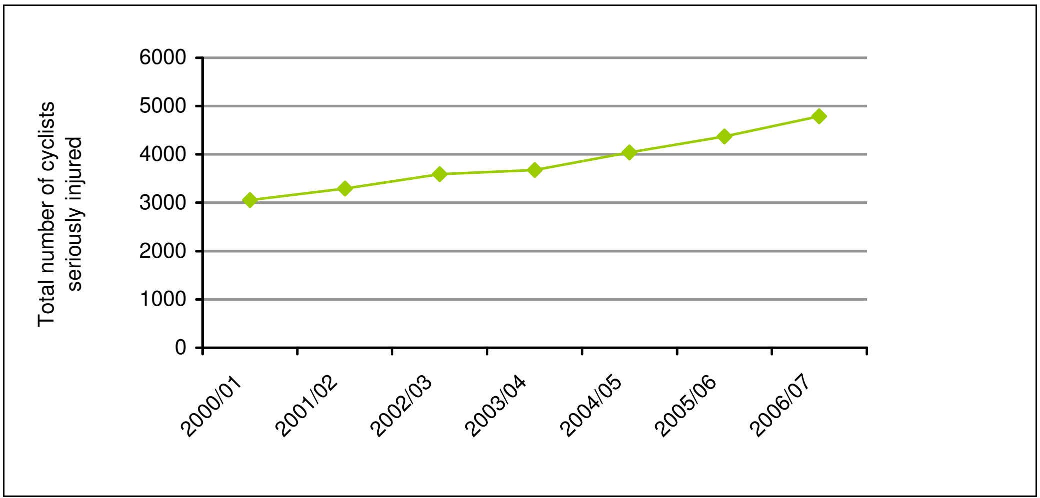

Figure 1-5 Number of cyclists seriously injured in road traffic crashes (Australia) (Created from Henley & Harrison, 2009)

The serious injury rate per 100,000 population was highest for car occupant (77.5), motorcyclist (35.3), cyclist (23.3) then pedestrian (13.5). The age standardised serious injury rate increased by 47 per cent for cyclists (including off-road crashes) from 2000/2001 to 2006/07. The same age standardised rate increase was reported for motorcyclists, yet for all other road users, only relatively small rate changes were reported (Henley & Harrison, 2009).

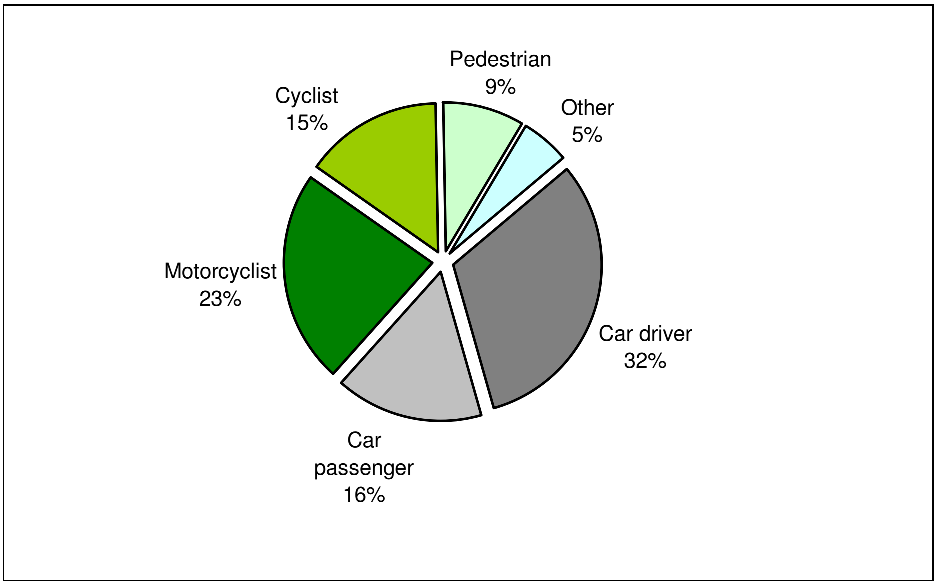

Figure 1-6 Serious injury due to traffic crash by road user group, 2006/07 (Created from Henley & Harrison, 2009)

Use of total population data as a denominator for crash and injury rates for cyclists has serious limitations. In particular, this approach is likely to underestimate cyclists' risk of serious injury in Australia, where there is a relatively low level of participation, as discussed in Section 1.1. In addition, population-based age standardised rates are also likely to be inaccurate for cyclist crashes as the age profile of riders does not match that of the general population. Data limitations are discussed further in Section 1.2.3.

Garrard and colleagues (2010) calculated relative risk for cyclist serious injury crashes in Melbourne and reported relative risk for cyclists compared with drivers of 13:1 based on police data and 34:1 based on hospital data. The authors acknowledged data limitations, including a lack of longitudinal cyclist travel data and advised caution in interpreting the findings. This study also identified a large discrepancy between hospital and police reports for cyclist crashes.

Efforts have been made to calculate nonfatal cyclist crash rates per kilometre travelled, however this has proven difficult. In addition to the limitations of participation or exposure data, there is no standard definition for injury severity. In Australia, as is the case internationally, the definition of a non fatal injury varies across states and territories. Notwithstanding this limitation, rates for several jurisdictions have been reported. Figure 1-7 shows the cyclist injury rates reported by Pucher and Dijkstra (2003) for the Netherlands, Germany and the US.

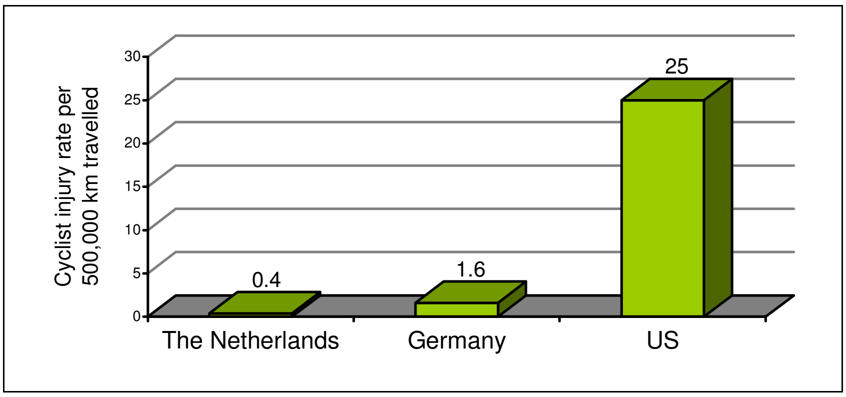

Figure 1-7 Cyclist injury rate per 500,000km travelled in the Netherlands, Germany and the US, 2000
(Created from Pucher & Dijkstra, 2003)

The trend for cyclist serious injury rates presented here show a similar pattern to fatality rates presented in Figure 1-4. Countries with higher cycling participation levels showed a lower rate of cyclist injury data per kilometre travelled. However, as noted above, the findings should be interpreted with some caution given the lack of standardisation in defining non fatal injury. Further, unlike fatality data, non fatal crash data are limited by underreporting and is reportedly unreliable, incomplete, non-representative and misleading (Harris, 1990; Pucher & Dijkstra, 2003).

While cycling participation in Australia is anecdotally comparable to the US, it is not possible to determine if the cycling injury rates per kilometre travelled in the US in Figure 1-7 are comparable to Australia.

In Australia, Watson and Cameron (2006) conducted a review of characteristics of police reported cyclist-driver fatal and serious injury crashes (n=13,901) in Victoria, South Australia, Queensland and Western Australia from 2000 to 2004. Data was not available from the other four Australian jurisdictions. Characteristics reported for fatal or serious injury crashes were similar to the national cyclist fatality crashes reported by the ATSB (2006). The greatest proportion of crashes occurred in speed zones up to 75km/h, during the day and in fine weather conditions. In addition, Watson and Cameron reported that the most severe cyclist injury outcome resulted from a collision involving a four-wheel drive vehicle. The role of vehicle type as a risk factor was considered in this doctoral research and findings are discussed in Chapter 8.

An important methodological issue raised by Watson and Cameron was the large proportion of missing data for cyclist crashes. The most notable gaps (classified as 'unknown') were: month of crash (47.5%), vehicle type (40.7%), day of week (17.7%), age of driver (15.9%) and age of cyclist (11.0%). These missing data may reflect inadequacies in the scope of the classification scheme, difficulties in implementation or interpretation of the classification scheme at the time of data recording, or a need for more reporting protocols for police reports.

Missing data in official reports compromises how the data can be used for injury prevention purposes, particularly in identifying factors that contributed to crashes. These data limitations are discussed in the next section.

1.2.3 Cyclist crash data limitations

Official cyclist crash datasets, including hospital, police and coronial reports are subject to a range of limitations that are problematic for injury analysis and interpretation. Four main limitations have been identified and these are discussed below.

Underreporting

Underreporting of cyclist crashes is a major limitation, especially for nonfatal crashes internationally and in Australia (Harris, 1990; Schlep & Ekman, 1990; Ameratunga, Hijar & Norton, 2006). Many researchers have cautioned against using official crash records to quantify or investigate cyclist crashes, due to the extensive underreporting (Bull, 1975; Lindqvist, 1991; Welander, Ekman, Svanstrom, Schelp & Karlsson, 1999; Stone & Broughton, 2003; de Lapparent, 2005; Gavin, Meuleners, Cercarekkum & Hendrie, 2005; Lujic, Finch, Boufous, Hayen & Dunsmuir, 2008; Sikic et al., 2009). Unlike cyclist fatality crashes, there is no legal requirement to report nonfatal cyclist crashes, to police, especially if there was no property (vehicle) damage. In a report by the Victoria Police, Harman conservatively estimated that only 1 in 30 nonfatal cyclist crashes is reported (Harman, 2007).

Drivers underreport incidents with vulnerable road users compared with reporting rates for vehicle-to-vehicle crashes (Joshi, Senior & Smith, 2001; Gavin et al., 2005). In New South Wales, a data linkage study of all road user crashes from police and hospital records found that driver-crashes were twice as likely to be matched as cyclist-crashes. Reasons for underreporting included lack of knowledge about reporting procedures and a lower incentive to report the crash for insurance purposes as there is usually limited property (vehicle) damage in a vehicle-bicycle collision (Lujic et al., 2008).

Underreporting is also a significant limitation for international data, including in the Netherlands (Harris, 1990), Sweden (Bull & Roberts, 1973; Lindqvist, 1991), France (de Lapparent, 2005), Canada (Aultman-Hall & Hall, 1998) and Hong Kong (Loo & Tsui, 2007). In the Netherlands, where there is high cycling participation and sophisticated knowledge of cyclists' behaviour, a linkage study of police records and self-reported injury crashes reported that only 11 per cent of reported cyclist crashes had a corresponding police report, compared with drivers (41%), motorcyclists (39%) and pedestrians (25%) (Harris, 1990). In Hong Kong, Loo and Tsui (2007) reviewed matched police and hospital data for all road crashes and concluded that the most serious underreporting was evident for cyclists. This gap in the official crash data is proposed as a major public health issue (Aultman-Hall & Hall, 1998; de Lapparent, 2005; Loo & Tsui, 2007). A number of recommendations have been made for increasing reporting including adding cyclists to existing injury surveillance surveys, linking general practitioner, hospital and police data, streamlining police reporting procedures and encouraging witnesses to report crashes to police (Harris, 1990; Loo & Tsui, 2007).

Purpose of crash data

The primary function of official police, hospital and coronial reports is to document information for the purpose of the judicial process or patient treatment and this dictates the type of data that is recorded. Data categories recorded do not include the detail necessary to determine all pre-event or systems factors that may have contributed to a cyclist crash.

Errors and bias

The official recorded account of all crashes is documented post-event and is generated from the account of the people involved. This is subject to numerous errors and biases, particularly in a cyclist fatality crash. Cyclist fatality crash details are based largely on the driver's account which may be subject to recall bias, or be incorrect due to shock or for fear of being deemed responsible (Conche & Tight, 2006). In a cyclist fatality crash when the driver and/or witnesses did not see the cyclist prior to the crash, information about the cyclist's behaviour pre-crash is completely absent (McCarthy, 1996).

Further, there is potential for errors in the processing of the crash report data. Under time pressures at a crash scene or in emergency departments where, rightly, patient care is the primary focus, there is room for human error in coding and data entry (Langley, Stephenson, Thorpe & Davie, 2006).

Lack of definitions

In Australia and internationally, as discussed above, there is no agreed definition for nonfatal injuries. This lack of consensus makes it difficult to make accurate comparisons of cyclist injury rates. In Australia, there is a lack of consistency in definitions between states and territories, which makes nonfatal injury data difficult to analyse even within Australia (Watson & Cameron, 2006).

Lack of participation data

Lastly, a serious limitation exists due to lack of participation data. As indicated previously, detailed data on cyclist participation, characteristics and exposure data including trip distance, trip purpose and hours travelled is essential for accurate interpretation of crash statistics. For example, the high proportion of males involved in crashes *may* be a function of exposure as more males cycle than females (males: 67%; females: 33%) (Department of Communications Information Technology and the Arts, 2009). In addition, males may cycle further than females, further increasing their crash exposure. Others have proposed that higher male cyclist crash involvement is due to differences in risk taking behaviour of males and females (Ameratunga et al., 2006; Garrard, Crawford & Hakman, 2006). Similarly, the over-representation of adult cyclists in both fatal and serious injury crashes compared with child cyclists may be due to more adults riding on the roads and being exposed to collisions with vehicles (Wachtel & Lewiston, 1994). Accurate exposure data is essential to advance our understanding of the relative risk status of different groups of cyclists.

Given the lack of reliable cyclist exposure data, it is difficult to determine the true risk of cyclist crashes or cyclists' relative safety in Australia (Garrard et al., 2010). Due to the extensive underreporting of nonfatal cyclist crashes, the actual cost burden of cyclist serious injuries is likely to be significantly underestimated. The cost of cyclist serious injuries is discussed in the next section.

1.2.4 Cost of cyclist serious injuries

The increase in the number of cyclist serious injury crashes has a significant financial cost attached. In an Australian study using New South Wales crash data, researchers concluded that the greatest burden of injury for cyclists was from collisions with motor vehicles (Chong et al., 2010). Estimates for the cost of road user crashes for a hospitalised injury was estimated at AUD$214,000 per person (including disability related costs) and a non-hospitalised injury was estimated at AUD$2,200 per person (Bureau of Infrastructure Transport and Regional Economics, 2006). Given that in 2006/07, 4,789 cyclists were seriously injured, using the lower BITRE injury cost estimate above of AUD$2,200 per person, this equates to over AUD$10.5 million in that year alone. With the increasing number of people cycling and the concurrent increase in cyclist serious injuries, this base figure of AUD$10.5 million represents a substantial public health concern.

A recent study in Belgium reported on minor cyclist crash costs in an attempt to create a more complete picture of the true costs of cyclist crashes (Aertsens, de Geus, Vandenbulcke, Degraeuwe, Broekx et al., 2010). In a prospective study of over 1,100 regular commuter cyclists, the authors reviewed the costs of 219 minor cyclist crashes and estimated a per crash cost of €841 (AUD$1,160). Almost half (48%) of the total cost of the minor crashes was in lost productivity. A similar dataset is not currently available in Australia to determine costs for minor cyclist crashes.

At the more severe end of the injury spectrum, injuries that result in lifelong disabilities have even greater associated costs (Holtslag, van Beeck, Lichtveld, Leenen, Lindeman et al., 2008). Additional costs can include psychological, social and legal costs, lost income, travel anxiety and ongoing pain (Mayou & Bryant, 2003). Indicative lifetime costs per person for a moderate traumatic brain injury are estimated at AUD$2.6 million with a spinal cord injury quadriplegia estimated at AUD$7.6 million (Access Economics, 2009).

It is clear from the review of cycling participation and cyclist crash data presented thus far, that the number of people cycling in Australia is increasing and so too is the number of cyclist serious injuries. The injury trend is of concern to individual cyclists and more broadly for public health authorities, and for the management of road safety. In the next section, the focus is shifted from the crash and injury patterns, to the road safety context in Australia and the impact of safety management strategies on cyclist safety.

1.3 Cyclist safety in Australia

In Australia, broad road safety initiatives have been developed with the aim of reducing road trauma. Key initiatives have focused on automated speed cameras, police enforcement of driver mobile phone use laws, and increased random driver testing for blood alcohol content and drug use. From 1990 to 1992, the number of cyclist fatalities decreased significantly (see Figure 1-3). While not explicitly directed at cyclists, it is likely that safety initiatives implemented over that period have contributed to the reduction of crashes involving all road users, including cyclists. In particular, two major road safety initiatives aimed at reducing the number of people who were driving with a blood alcohol content over the legal limit (0.05) (December 1989) and reducing the number of people driving over the speed limit (March 1990) (Cameron, Helman & Neiger, 1992).

The most significant cycling specific directive in the early 1990s, arguably of any time in Australia, was the introduction of compulsory bicycle helmet use legislation. Unlike the broad road safety countermeasures that aimed to reduce crashes, the aim of the legislation was to reduce the severity of cyclist head injuries in the event of a crash. Australia remains one of the few countries in the world to have compulsory bicycle helmet use legislation for cyclists of all ages. The safety implications of bicycle helmet use are discussed in the following section.

1.3.1 Bicycle helmet use

Australia was the first country to introduce compulsory bicycle helmet use legislation, beginning in Victoria on 1 July 1990 (Cameron et al., 1992) and implemented nationally by the end of 1992. The impact of the legislation was closely monitored to identify any changes in the injury profile of cyclists. In the years before and after the introduction of the legislation, there were numerous reports that addressed the use, effectiveness and performance of bicycle helmets (Finch, Heiman & Neigher, 1993; Cameron, Finch & Vulcan, 1994; Finch, Cameron, Vulcan, Finch & Newstead, 1994; Newstead, Cameron, Gantzer & Finch, 1994; Carr, Skalova & Cameron, 1995).

The use of bicycle helmets by cyclists is widely supported amongst the injury prevention and health promotion communities. Health care professionals and the World Health Organisation are emphatic in their support for increased helmet use to reduce the severity of cyclist head injuries (Runyan & Runyan, 1991; Liller, 2000; Heng, Lee, Zhu, Tham & Seow, 2006; World Health Organisation, 2006). Even in countries with high cycling participation, where helmets are not mandatory, such as Sweden, Germany and Belgium, there is increasing support for helmet use (Oström, Bjornstig, Naslund & Eriksson, 1993; Ekman & Welander, 1998; Zentner, Franken & Lobbecke, 1998; Depreitere, Van Lierde, Maene, Plets, Vander Sloten et al., 2004; Richter et al., 2007).

Numerous review articles have been published on the efficacy of bicycle helmets. In Australia, a meta-analysis by Attewell, Glase and McFadden of 16 articles concluded that ‘the evidence is clear that bicycle helmets prevent serious injury and even death’ (Attewell, Glase & McFadden, 2001:345). A Cochrane review article by Australian researchers of 5 studies reported that compulsory bicycle helmet use legislation is effective in increasing helmet use and decreasing head injuries (Macpherson & Spinks, 2007). A separate Cochrane review of 5 case-control studies found that helmets provide a 63-88 per cent reduction in head injury and severe brain injury for all cyclists and are protective against cyclist head injuries in vehicle and non-vehicle crashes (Thompson, Rivara & Thompson, 2009). The need for legislation to increase helmet use was reported in research conducted in Canada (Karkhaneh, Kalenga, Hagel & Rowe, 2006), Singapore (Wong, Leong, Anantharaman, Raman, Wee et al., 2002) and the US (Haileyesus et al., 2007).

Despite the extensive evidence of the efficacy of helmets in reducing serious head injuries, anti-helmet proponents argue that compulsory helmet use legislation causes a reduction in the number of people cycling, as cycling will be perceived as dangerous (Robinson, 2006). This in turn, Robinson argued, reduces the overall health benefits of cycling and the safety in numbers effect (Robinson, 2005). However, a systematic review by Karkhaneh and colleagues (2006) of 11 studies concluded that there was insufficient detail available to support the claim that helmet legislation resulted in reduced participation (Karkhaneh et al., 2006). Similarly, Macpherson and Spinks (2007) concluded that there is no evidence to support or refute the claim that helmet legislation leads to a reduction in cycling participation.

Controversy about helmet use and legislation is likely to continue and further discussion is outside the scope of this doctoral thesis. There is extensive research that addresses the efficacy of helmets in reducing the severity of head injuries and several researchers who dispute the need or efficacy of helmets. A summary of selected helmet-related publications is included in Table 1-1.

1.3.2 Cycling policy in Australia

In Australia, as in the US and the UK, it has been proposed that government policies have given 'the green light to the private car, almost regardless of its economic, social and environmental costs' (Pucher & Buehler, 2008b:4). This car culture underlies the belief that roads are made and operate for motorised vehicles which places drivers in a position of power and marginalises non-drivers on the road.

Despite this car-centric culture (Garrard et al., 2010), Australia does have a national cycling policy, however, the main focus of the policy is on participation. The National Cycling Strategy (NCS) (2005-10) is the cycling policy document produced by Austroads, the peak body for road transport and safety in Australia. Recommendations include increased monitoring of participation, implementing cycling infrastructure and facilities, and blackspot road works.

In terms of safety issues, the emphasis presented in the NCS is on cyclist responsibility. Recommendations include: bike handling skills training, increased conspicuity and helmet use. General references are made about education of other road users, however, no specific actions are detailed (Austroads, 2005).

Table 1-1 Summary of selected bicycle helmet related research

Author(s) & Year	Location	Methods/participants	Key outcomes
Waters, 1986	UK	Hospital data n = 506 cyclists	Cyclist helmets recommended to improve survival rates from head injuries
Dorsch, Woodward & Somers, 1987	South Australia, Australia	Questionnaire n = 894 cyclists	Helmets determined to be protective in a crash involving a head strike ▪ 197 cyclists crash had head injury (62%) wore a helmet, estimated 90% of deaths due to head injuries would have been prevented with hard helmets
Wood & Milne, 1988	Victoria, Australia	Review of helmet campaigns, injuries, helmet use surveys	Cyclist-driver crashes, 1982/83 to 1984: helmets attributed to 20% reduction in cyclist head injuries Design standard is important, commuter helmet use ↑ 1983 (26%) to 1986 (44%)
July 1990 – compulsory bicycle helmet use legislation introduced in Victoria			
Sacks, Holmgreen, Smith & Sosin, 1991	US	Analysis of hospital and coronial data 1984-1988	▪ Majority of fatalities involved a head injury 2,985 (62%); 87% with car ▪ No helmet = ↑ relative risk of 6.67 for head injury ▪ 84% of head injury fatalities could be prevented with helmet use
Cameron, 1992	Melbourne, Victoria, Australia	Observations, cyclist injury data	▪ Helmet use ↑ pre-leg'n 1982/83: 5%: 1989/90: 31%; 1 yr post-leg'n ↑ 75% ▪ Cyclist participation changes: children ↓ 36%, adults ↑ 58% ▪ 1989 to 1991 = significant ↓ head injuries due to legislation and ↑ helmets
December 1992 – compulsory bicycle helmet use legislation introduced in all Australian jurisdictions			
Finch, Heiman & Neiger, 1993	Melbourne, Victoria, Australia	Manual observational study	Helmet use ↑ post-legislation all ages, adults 1990: 36%; 1991: 74%; 1992: 84% Legislation ↓ cycling participation, 2 yrs post-legislation cycling participation close to pre-legislation
Hillman, 1993	UK	Review of cycling policy and health promotion	Landmark article, 'benefits gained from regular cycling outweigh the loss of life in years in cycling fatalities by a factor of around 20 to 1' (p55) The statement does not specifically relate to helmet use or non-use, however is subsequently used as evidence to reject helmet use
Carr, Skalova & Cameron, 1995	Victoria, Australia	Analysis of hospital injury data	Four years post-legislation Hospital admissions in the 4 years post-legislation were 40% below the number expected based on the pre-legislation trends

Table 1-1 Summary of selected bicycle helmet related research, continued

Author(s) & Year	Location	Methods/participants	Key outcomes
Robinson, 1996	New South Wales, Australia	Analysis of previous cyclist helmet studies	Helmets discourage cycling; draws causal link between helmet use and reduced cycling/societal levels of obesity. No evidence of causation is provided. Claims helmet injury risk similar for unhelmeted cyclists and drivers
Scuffham, Alsop, Cryer & Langley, 2000	New Zealand	Survey helmet use, analysis of hospital data	Three years post-legislation in New Zealand Helmet use attributed to 19% reduction in cyclist head injury
Attewell, Glase & McFadden, 2001	Australia	Meta analysis, 16 articles	Conservative risk reduction estimates for helmet use to reduce the risk of: head injury, 45%; brain injury, 33%; facial injury, 27%, and; fatal injury by 29% Cyclist helmet use analogous to car occupant seat belt use
Nolén & Lindqvist, 2002	Sweden	Evaluation of helmet use	Caution against child-focused helmet uses programs, helmets needed for all cyclists Aim of Swedish National Road Administration = 80% helmet use for all cyclists, usage rates were: children 50%, adults 10-15%
Hamilton & Stott, 2004	UK	Review of cyclist injury data and cycling risks	British Medical Association recommendation for helmet use by all cyclists Broader cyclist safety considerations needed, e.g. traffic calming, end of trip facilities
Macpherson & Spinks, 2007	Australia	Cochrane review	Legislation is effective in increasing helmet use and decreasing head injuries Insufficient evidence to support or negate claims that bicycle helmet law leads to a reduction in cycling participation
Curnow, 2003, 2005, 2006, 2007	Australia	Brief communications etc.	Anti-helmet use papers, disputes previous research. Claims: 1) researchers don't account for mechanism of brain injury; 2) case-control studies inadequate
National Highway Traffic Safety Administration (NHTSA), 2008	US	Fact sheet	Majority (70%) of all fatal cyclist crashes involved head injuries Estimates helmet use (4-15 yrs) would ↓ 39,000-45,000 head injuries annually At 2008 US state helmet laws, 14 states = no law, other states = child only
Thompson, Rivara and Thompson, 2009	US	Cochrane review article 5 articles	Helmets provide 63-88% reduction in head severe brain injury for all cyclists Helmets are protective for cyclists in vehicle and non-vehicle crashes

As identified in the crash data review in Section 1.2 above, the majority of cyclist fatality crashes involve vehicles. It is likely that drivers have a greater role in cyclist safety than is suggested in the NCS. The role of drivers in cyclist safety was a central component of this doctoral research.

There is evidence that government departments are supportive of cycling at a strategic policy level, with cycling promoted as a positive activity that will benefit Australia across many domains including environmental sustainability (Department of the Environment, 2010), health (Standing Committee on Health and Ageing, 2009) transport as well as the social and access benefits of cycling (Department of Infrastructure, 2002). In essence, these policies present bicycle riding as an activity that requires infrastructure support, individual motivation and road user responsibility. The role of driver behaviour, cyclist-driver interaction and the effect of cycling-related on-road facilities are clearly central to the understanding of cyclist safety and were investigated using several methodological approaches in this doctoral research, see Chapter 7, Chapter 8 and Chapter 9.

Summary

In summary, limited information is available on cycling participation in Australia; however the available data indicates that the number of cyclists is increasing. In 2009, over 1.9 million people aged over 15 years in Australia rode a bike with 23.5 per cent riding 3 or more times per week. In Melbourne, in 2008, cyclists represented 8 per cent of sampled morning traffic into the CBD during peak travel times and morning cyclists to the Melbourne CBD increased by 20 per cent from 2009 to 2010.

Cycling as a mode share in Australia is significantly lower compared to international cycling participation levels, particularly in many European countries. International examples of cyclist-inclusive strategies from Europe and South America may contribute to greater cycling participation in Australia.

The cyclist crash data reviewed in this chapter showed a reduction in cyclist fatalities over the last 30 years in Australia, however this plateaued in 2005. In Melbourne, the relative risk of a fatality per kilometre travelled when cycling compared to driving was between 5 and 19. Cyclist serious injury crashes increased by 14 per cent from 2000/01 and 2006/07. The relatively low levels of cycling participation and the concurrent increases in cyclist serious injury crashes suggest that it is unlikely that the safety in numbers effect is applicable in Australia at the present time. Cost estimates for cyclist serious injuries were upwards of AUD$10.5 million in 2006. Cyclist fatalities and serious injuries are a significant public health issue for public health authorities and the management of road safety.

Significant gaps and limitations were identified in the official cycling participation and crash data. Lack of detailed exposure data is a significant issue, as it is not possible to accurately calculate the rate of cyclist fatality or serious injury by kilometre travelled, an important measurement of cyclist safety. In addition, data limitations need to be addressed including: underreporting, errors and biases and consensus is needed on a definition of injury.

In Australia, compulsory helmet use legislation was introduced in the early 1990s and widely supported in the literature. However, there is some conjecture about the efficacy of helmets and the impact of the legislation on participation. Australian cycling policy has mainly focused on cycling participation. Cyclist safety has been the responsibility of the cyclist with minimal acknowledgement of the role of the driver. The role of the cyclist *and* driver, and their interaction were key factors explored in this doctoral research.

1.4 Thesis structure

This thesis is submitted as a PhD by publication. The format follows the traditional thesis structure with five publications included as chapters. Each paper is submitted in its published format as per the requirements of Monash Univesity. Hence, inherently, the structure of the thesis has a small element of repetition of information across the publications presented in the thesis chapters. All efforts have been made to minimise duplication.

Four of the included papers have been peer-reviewed and published. At the time of printing, the fifth paper was submitted to the peer-reviewed journal, *Social Science and Medicine*. Each paper is prefaced by a brief introduction and a Declaration of Thesis Chapter signed by all the authors. Throughout the thesis, 'the researcher' refers specifically to Marilyn Johnson, the PhD candidate.

Following the introductory chapter presented here, Chapter 2 provides a review of the published literature related to the main contributing factors for cyclist-driver crashes and the research questions for the research program are presented. In Chapter 3, the methodological approach is presented and the theoretical framework for the research, the Safe System Framework, is outlined.

The research was undertaken in three stages. Chapters 4 to 9 present the research activities, data collection, analysis and results. In Chapter 4, Stage 1 is described, which was an observational study of cyclist-driver behaviour at intersections using a fixed video camera. Two publications resulted from this research stage and are presented in Chapter 5 and Chapter 6. Stage 2 was a naturalistic cycling study. Compact video cameras were mounted to commuter cyclists' helmets who recorded their trips to and from work. The method was adapted from a naturalistic driving study and was used to investigate cyclist-driver interactions, collisions and near-collisions. The method for the naturalistic cycling study is presented in Chapter 7 and the results are presented in Chapter 8. Stage 3 involved an online survey of both cyclists and drivers. The publication arsing from this study focused on driver behaviours, knowledge and attitudes and is presented in Chapter 9.

Chapter 10 is the discussion chapter which includes a synthesis of the findings of the three research stages, recommendations for how cyclist safety may be improved and final conclusions for this doctoral research.

Chapter 2

Literature review

The literature reviewed in Chapter 1 provided an indication of the number of cyclist fatal and nonfatal crashes and the financial burden to the community of on-road cyclist crashes in Australia. In this chapter, the literature on cyclist-driver crashes was reviewed and contributory factors in cyclist-driver crashes are examined. Finally, the scope of the doctoral research is described and the research questions are presented.

To identify the relevant literature, a library search was conducted of academic journals, conference proceedings and non-peer reviewed reported published online. The following online search engines were used: ScienceDirect, MedLine, PsychInfo, SafetyLit, ATRI, Scirus and GoogleScholar. Key terms searched included: *cyclist*, *bicycle* and *cycling* and variations such as pedal cyclist, bicyclist, bike; and these terms were used in combination with *drivers*, *motorists*, *safety, crashes, collisions, near-collisions, behaviour*, *infrastructure, facilities, safe system, traffic* and *interactions*. Studies that focused solely on child riders or off-road locations such as bike paths, recreational trails and footpaths were excluded from the review.

2.1 Understanding cyclist-driver crashes

A key to identifying ways to improve safety for on-road cyclists is to understand when and under what conditions cyclist crashes occur (Gordon, 1949). The focus of this review was on the factors that contributed to the crash that is the *pre*-crash details.

A considerable body of research was identified for the review. A particular emphasis was given to studies that investigated cyclist fatal and nonfatal crashes using police reports (Atkinson & Hurst, 1983; Stone & Broughton, 2003; de Lapparent, 2005; Kim, Kim, Ulfarsson & Porrello, 2007), hospital records (Rivara et al., 1997; Welander et al., 1999) and coronial reports (Rowe, Rowe & Bota, 1995; National Coroners Information System, 2006). Typically, these studies provided data on the crash site and surrounding road environment; vehicle details (if involved); an account from the driver involved and, in some cases, the cyclist and witnesses; gender and demographic details (Lindqvist, 1991; McCarthy & Gilbert, 1996; Gavin et al., 2005; Lujic et al., 2008; Loo & Tsui, 2010).

The literature search returned 169 articles. Studies that did not provide information on contributing factors for adult cyclist-vehicle crashes were excluded. Excluded publications mainly focused on: post-crash factors such as cyclist injury outcomes (Olkkonen, Lahdenranta, Slatis & Honkanen, 1993; Viano, von Holst & Gordon, 1997; Rosenkranz & Sheridan, 2003); ecological level trend analysis (Friede, Azzara, Gallagher & Guyer, 1985; Rodgers, 1995; Finch, Valuri & Ozanne-Smith, 1998; Welander et al., 1999; Mohan, 2002; Cassell, Finch & Stathakis, 2003; Javouhey, Guerin & Chiron, 2006; Lujic et al., 2008; Henley & Harrison, 2009); or data linking (Bull & Roberts, 1973; Harris, 1990; Gavin et al., 2005). Foreign language publications (Wang, Wang & Chi, 1997) were also excluded from the review.

In total, 19 articles were identified that included details on pre-crash contributing factors in cyclist-driver crashes. The articles are summarised and the main contributing factors are presented in Table 2-1.

Table 2-1 Summary of selected research that investigated cyclist-driver crash contributing factors

Author(s) & Year	**Location**	**Methods/participants**	**Contributing factors (CF)**
Atkinson & Hurst, 1983	New Zealand	Police data, 1978 n=692 cyclists	CF: driver distraction/driver inattention, cyclist swerved around road defect Responsibility, driver: fatal 41%, nonfatal 51% - 33% did not see Responsibility, cyclist: fatal 51%, nonfatal 45%
Ballham, Absoud, Kotecha & Bodiwala, 1985	UK	Prospective study Feb-July 1983 n=382 cyclists	CF: rider error, 53%; bike failure, mechanical, 13%; driver error, 16% 34% of cyclists 18+ yrs, no differentiation of causes for adults/children
Lawson, 1991	UK	Police data and site analysis 1985 – 1990	CF: red light infringement, cyclist infringed 1.8% (n=9), driver infringed 3.2% (n=15)
Simpson & Mineiro, 1992	UK	Prospective study 29 months to May 1985 n=1,831 cyclists (417 adult cyclists)	CF: other road user (41%), cyclist error (39%), environmental (12%) Frequent cyclist error crash due to item (bag) caught in the front wheel
Rowe, Rowe & Bota, 1995	Canada	Retrospective case series Coronial data 1986-1991 n=212 cyclists	CF: driver failed to see cyclist (64%); cyclists aged: 20-44yrs = driver error (63%); 45+yrs = cyclist error (44%) Most fatalities occur during the day (69%); majority fatalities involved a vehicle (91%)
McCarthy & Gilbert, 1996	UK	Police and coronial data 1985-1992 n=124 cyclists	CF: driver overtaking cyclist did not give sufficient clearance, heavy goods vehicles (HGV) (suction can throw cyclists off balance), driver turning left ; 6.5% of drivers 'didn't see' cyclists, of those cases 75% cyclist in driver's blind spot; 23% = failure to give way, 50-50 cyclists and driver
Summala, Pasanen, Räsänen & Sievanen, 1996	Finland	Observations at T-intersections with cycle paths n=111 drivers	Drivers visual scanning concentrates on direction of major threat
Rivara, Thompson & Thompson, 1997	US	Case-control March 1992- Aug 1994 n=3,849 cyclists	CF: Speed, cyclist and driver

Table 2-2 Summary of selected research that investigated cyclist-driver crash contributing factors, continued

Author(s) & Year	Location	Methods/participants	Contributing factors (CF)
Räsänen & Summala, 1998	Finland	Police data n=188 cyclist-driver crashes	CF: driver did not notice cyclist, did not realise danger, did not have time to react, confusion about priority
Räsänen & Summala, 2000	Finland	Observations cyclist-driver interactions at roundabouts n=2,152	CF: drivers mainly looked in direction they yielded to (right in Australia); vehicle speed
Stone & Broughton, 2003	UK	Police data 1990-1999 n=1,108 cyclists	CF: speed, cyclist avoidance action with one vehicle (parked) leads to crash with second vehicle Majority of crashes occurred at or near intersections
Herslund & Jørgensen, 2003	Denmark	Self-reported near-collisions n=8 drivers, 2 cyclists	CF: drivers fixed routine for visual search strategies on familiar routes, especially for experienced drivers Drivers give ↑ margin for cyclists when another vehicle present than cyclist alone
Green, 2003	Australia	Police data and observations	Cyclist red light infringement was 6% of all infringement related crashes Cyclists were 0.6% of all road users observed to infringe at red lights
de Lapparent, 2005	France	Police data 2000 n=918 cyclists	CF: vehicle speed, driver distraction/inattention
Walker, 2005	UK	Simulator experiments, drivers at T-intersections N=25 drivers	Cyclist arm signals (turning) reduced driver response time and affected probability of stopping in time when cyclist at risk
Australian Transport Safety Bureau, 2006	Australia	Police and coronial data 1991 - 2005 n = 665 cyclists	CF: failure to see (cyclist and driver) (34%), misjudgement, cyclist or driver (10%), cyclist responsible (60+%), weather mainly fine (86%), Males overrepresented; Most frequent crash type: cyclist hit from behind vehicle travelling in same direction
National Coroners Information System, 2006	Australia	Coronial data 2004	CF: driver failure to see; cyclist insufficient lights/dark clothing; driver turned in front of cyclist

Table 2-2 Summary of selected research that investigated cyclist-driver crash contributing factors, continued

Author(s) & Year	Location	Methods/participants	Contributing factors (CF)
Haileyesus, Annest & Dellinger, 2007	US	Hospital data 2001-04 n=62,267 cyclists	CF: sideswiped by a moving vehicle, swerving to miss a vehicle that passed too closely and hit another vehicle, collision with vehicle doors being opened
Kim, Kim, Ulfarsson & Porrello, 2007	US	Police data 1997-2002 n=2,934 cyclists	CF: inclement weather, darkness with no streetlights, am peak traffic period, head-on collision, speeding, vehicle speed over 48.3km/h, truck, intoxicated driver/cyclist, cyclist aged over 55 years
Schramm, Rakotonirainy & Haworth, 2008	Australia	Police data 2000-05 n=1,317 cyclists	CF: when driver at fault: disobeyed traffic control (28%), undue care/inattention (20%); when cyclist at fault: inattention/negligence (35%), disobeyed traffic control (13%) Fault correlated with age, cyclists aged 30-59yrs at fault <20% of crashes

The review identified several contributing factors in common, across the studies and across study sites with varying levels of cycling participation. In particular, these were: cyclist error (Australian Transport Safety Bureau, 2006; Schramm, Rakotonirainy & Haworth, 2008); low cyclist visibility at night (Rowe et al., 1995; National Coroners Information System, 2006); drivers' failure to see cyclists (Rowe et al., 1995; McCarthy & Gilbert, 1996; Summala, Pasanen, Räsänen & Sievanen, 1996; Räsänen & Summala, 1998, 2000; Herslund & Jørgensen, 2003; Walker, 2005; Australian Transport Safety Bureau, 2006; Schramm et al., 2008); driver distraction/inattention (Atkinson & Hurst, 1983; de Lapparent, 2005; Schramm et al., 2008); and vehicle speed (Stone & Broughton, 2003; de Lapparent, 2005). This suggests that some of the pre-crash contributing factors in cyclist-driver crashes may be universal.

To create structure for the review, the contributing factors were organised into five groups: cyclist, driver, roads, vehicles and other factors. A summary of the studies and their findings with respect to contributing factors and recommendations is presented in Table 2-2.

Table 2-2 Summary of the main contributing factors identified for cyclist-driver crashes

Contributing factors	Author(s) & Year
Cyclist	
Did not see driver	ATSB, 2006
Non-compliance with traffic control	Lawson, 1991; Green, 2003; Schramm et al., 2009
Error: misjudgement, inattention, negligence	ATSB, 2006; Schramm et al., 2009
Avoidance action (manoeuvring to avoid opening car door)	Haileyesus et al., 2007
Gender: male cyclists overrepresented in fatality crashes	ATSB, 2006
Bicycle mechanical failure	NCIS, 2006
Low visibility at night (driver did not see cyclist)	Rowe et al., 1995; NCIS, 2006; Kim et al., 2007

Table 2-2 Summary of the main contributing factors identified for cyclist-driver crashes, continued

Contributing factors	Author(s) & Year
Driver	
Did not see cyclist	Rowe et al., 1995; McCarthy & Gilbert, 1996; Summala, et al., 1996; Räsänen & Summala, 1998; Räsänen & Summala, 2000; Herslund & Jørgensen, 2003; Walker, 2005; ATSB, 2006; Schramm et al., 2008
Unprepared to see cyclists on road	Rowe et al., 1995; Simpson & Minero, 1992
Distraction/inattention	Atkinson & Hurst, 1983; de Lapparent, 2005; Schramm et al., 2009
Overtaking cyclists	McCarthy & Gilbert, 1996. Walker, 2007
Non-compliance with traffic control	Lawson, 1991; Schramm et al., 2009
Inadequate indicator time	NCIS, 2006
Roads	
Vehicle speed	Stone & Broughton, 2003; de Lapparent, 2005
Cyclist manoeuvring e.g. road surface defect or debris	Atkinson & Hurst, 1983
Vehicles	
Vehicle design	NCIS, 2006
Other factors	
Inclement weather	Kim et al., 2007

Study findings for each of the five groups of contributing factors summarised in Table 2-2 are discussed in the following sections.

2.1.1 Cyclist contributory factors in cyclist-driver crashes

Seven cyclist-related factors that contributed to cyclist-driver crashes were identified in this review. These were:

- did not see driver
- disobeyed traffic control
- error: misjudgement, inattention/negligence
- avoidance action (manoeuvring to avoid opening car door)
- gender
- bicycle mechanical failure
- low visibility at night (driver did not see cyclist)

2.1.1.1 Did not see driver

In a recent comprehensive analysis of fatal cyclist-driver crashes in Australia, both cyclist and driver failure to see was reported to be a factor in a third (34%) of crashes (Australian Transport Safety Bureau, 2006). However, the authors did not differentiate between the proportion of cyclists and drivers who failed to see and details were not provided about how the cyclists' looking behaviour was ascertained.

Over the last decade an increasing number of studies have investigated the role of failure to see, particularly looked-but-failed-to-see in cyclist-driver crashes. However, most of the research attention has been on drivers' looking behaviour, rather than cyclists' (Summala et al., 1996; Räsänen & Summala, 1998, 2000; Herslund & Jørgensen, 2003; Walker, 2005). The literature on driver looking behaviour is reviewed in Section 2.1.2.1. Despite the conclusion in the official report of fatal cyclist crashes (Australian Transport Safety Bureau, 2006) that cyclist failure to see is a contributing factor, there has been little research into cyclist looking behaviour.

While there has been little research on cyclist looking behaviour in relation to crashes, there has been some research that has investigated the cyclists' point of view. Researchers in the UK used compact video camera mounted to bicycle helmets to investigate experiences of mountain bike riding (Brown, Dilley & Marshall, 2008) and city cycling (Brown & Spinney, 2010). Benefits of the passive *in situ* recording were that it eliminated the need for participants to recall their experiences which removed a potential recall bias. In addition, researchers were not reliant on the cyclists' memory of events, this is important as the riders may not remember, nor have been fully cognisant, of all occurrences along their trip (Brown & Spinney, 2010).

However, the focus of these studies was cyclists' experiences and the footage was not analysed to deconstruct cyclist-driver crashes. In this review, no published studies were found that had used point of view cameras to understand cyclist-driver crashes. More importantly, no studies were found that specifically addressed the role of cyclist looking behaviour on crash risk. This method, using a point of view camera, was used in Stage 2 of the doctoral research to investigate cyclists' looking behaviour in cyclist-driver interactions, collisions and near-collisions. Details of this study are described in Chapter 7 and Chapter 8.

2.1.1.2 Disobeyed traffic control

Cyclist infringement at red traffic lights is arguably the most overt illegal cycling behaviour. However, in terms of safety, this behaviour has been reported as a causal factor in only a small number of crashes.

A review of 508 police reported crashes (n=382 cyclists) in the UK involving red light infringement found that 1.8 per cent were due to cyclist infringement (Lawson, 1991). A review of 1,317 police reported crashes in Queensland, Australia identified 1,214 cyclist-driver crashes. Of the cyclist-driver crashes, 6.5 per cent of crashes involved a cyclist who had infringed at a red light (Schramm et al., 2008).

Green reported on all road user red light infringement in an analysis of crash data from Queensland and an observation study in Victoria. Of 2,008 injury crashes resulting from a red light infringement, cyclist infringement comprised 6 per cent of all infringement. The majority of crashes involved driver infringement (84%). In an observational study in Victoria, (13 sites in Melbourne and 2 sites in Bendigo, a regional city), three fixed video cameras were positioned to record different angles of the targeted intersection and a total of 120 hours were observed. Only 3 cyclists were reported to infringe at the red light which represents 0.6% of all road users observed, again significantly fewer than the drivers observed infringing (86.6%) (Green, 2003).

While these studies provide data on cyclist infringement as proportion of all road user crashes, the studies did not provide any details on the total number of cyclists observed or an indication of the extent of cyclist red light infringement behaviour. Without the rate of red light infringement as a proportion of all cyclists who faced a red light it is not possible to determine the relative risk of this behaviour on safety – for cyclists or other road users.

Several observational studies have reported the rates of cyclist red light infringement, and the observed rate is consistently reported fewer than 10 per cent. In an observational study of cyclists at intersections in three US states, Hunter and colleagues (1999) reported that 8.4 per cent of cyclists infringed at the signalised intersections, while over a quarter (25.3%) of cyclists failed to stop at a stop sign (Hunter, Stewart, Stutts, Huang & Pein, 1999). Similarly in an observational study in Melbourne, 9 per cent of cyclists infringed at the red light. Cycling infrastructure (a painted bike box) was subsequently installed at the observational site, however this did not alter the observed rate of cyclist infringement (Daff & Barton, 2005).

In contrast to these low reported levels of cyclist red light infringement, are infringement rates for one specific type of cyclist: cyclists who ride in groups, or bunch riders. These groups, typically riding for training/fitness can reach over 100 riders in size. A review of bunch riders' behaviour at red lights was commissioned by the Victoria Police following the death of an elderly pedestrian who died after being struck by a group of cyclists who had infringed a red light at a pedestrian crossing. Victoria Police provided for analysis video footage of cyclists riding along the route both before and after the pedestrian fatality. In the footage recorded before the fatality, the observed bunch riders rode through almost half (46%) of the red lights they faced. In contrast, in the video footage recorded after the fatality crash *all* observed cyclists complied at *all* (100%) of the signalised intersections (Johnson, Oxley & Cameron, 2009).

However, there were significant methodological inconsistencies across the pre-post data collection periods that were outside the control of the researchers. These inconsistencies are likely to have lead to biases in the outcome behaviours observed at the two data collection periods and therefore the findings should be interpreted with some caution. Importantly, pre-collision footage was recorded from an unmarked vehicle that followed cyclists while the post-collision footage was recorded from a police helicopter that flew over the cyclists during their trip. Further, marked police vehicles were on the roads during the post-collision trips (Johnson et al., 2009). In addition, there was extensive anti-cycling media immediately following the collision and at the time of the coronial hearing (Medew, 2007; Oakes, 2007; Bibby, 2009). In the media, particularly in Melbourne, cyclists have been widely criticised for excessive red light infringement (Harrison, 2007; Bibby, 2009; Rennie, 2009). Notwithstanding the limitations of the study by Johnson et al. (2009), increased police presence and public awareness messages appear to have had a positive effect on bunch cyclists' compliance at red lights.

Overall, the research shows a wide variation of estimates of the extent of red light infringement by cyclists making it difficult to accurately establish the relative contribution of this factor to cyclist-drivers crash risk. The rate of cyclist red light infringement and the characteristics of non-compliant cyclists were an important focus in this doctoral research and the research addressing this issue is presented in Chapter 5.

2.1.1.3 Error: misjudgement, inattention/negligence

Cyclists' pre-event error is another contributing factor in cyclist-driver crashes identified in recent studies. An analysis of national cyclist fatality crashes determined that the cyclist's action was a causal factor in over 60 per cent of crashes (Australian Transport Safety Bureau, 2006). Schramm and colleagues (2009) also identified cyclist error as a contributing factor in their analysis of police data of predominantly nonfatal cyclist crashes.

These reports described cyclist error as including rider misjudgement, inattention or negligence, however, no additional details were provided about the behaviour. Furthermore, no information was provided about the catalyst for the cyclists' behaviour. It is not known if the error was due to the cyclist or in reaction to actions of other road users, the road environment or other factors.

2.1.1.4 Avoidance action

Cyclists' action in avoiding one potential crash has been found to be a contributing factor in a second crash event. Haileyesus, Annest and Dellinger (2007) identified that cyclists' swerving in reaction to adjacent traffic or an opening car door was a contributing factor as the cyclist then went on to fall or hit another vehicle (Haileyesus et al., 2007). The authors analysed records for 62,267 nonfatal cyclist crashes in the US from 2001 to 2004 and this action contributed to 6.1 per cent of nonfatal crashes. This equates to an estimated 3,812 crashes annually. The authors recommended more bicycle-inclusive road design that enhances how cyclists and drivers share the road, and potentially increase cyclists' safety. The role of road design and in particular cycling facilities are discussed later in this chapter.

As discussed in Section 2.1.1.1 little is known about cyclists' behaviour pre-event. To address this gap in the knowledge, cyclists' behaviour in the moments preceding a cyclist-driver crash, including cyclists' errors and avoidance behaviours were investigated in Stage 2 of this doctoral research and is presented in Chapter 7 and Chapter 8.

2.1.1.5 Gender

In Australia, males are overrepresented, both as a proportion of cycling participation (67%) (Department of Communications Information Technology and the Arts, 2010) and fatality crashes (83% of fatalities in 2009) (Department of Infrastructure, 2010). This overrepresentation in crashes may be a function of more males cycling, different patterns and location of riding, as well as behavioural and attitudinal differences.

In Australian research, researchers have investigated gender and cycling. Garrard, Crawford and Hakman (2006) in a study of female's cycling participation found that all cyclists expressed concern about cycling in traffic, aggression from drivers and inhaling exhaust fumes. However, these concerns were significantly more important for females than males (Garrard et al., 2006). In study in Melbourne, Garrard, Rose and Lo (2008) reported clear gender differences in route preference as female cyclists preferred a higher level of separation from traffic than male cyclists. More females used off-road bike paths than roads, with or without a bike lane compared with male riders (when adjusted for distance) (Garrard, Rose & Lo, 2008).

Gender differences in cycling behaviour were also reported by Peterson, Brazeal, Oliver and Bull (1997) using a bike simulator experiment in the US. Participants rode a stationary bicycle and responded to a series of four simulated crashes as if they were experiencing the events and post-test participants responded to the imagined scenarios using Likert scales to measure their fear and exhilaration to the imagine collision and the imagined near-collision. Female participants were reported to brake sooner, anticipate more fear and pain and less exhilaration than the male participants (Peterson, Brazeal, Oliver & Bull, 1997).

The role of cyclists' gender as a contributing factor in cyclist-driver crashes was investigated in this doctoral research. Gender was included as a variable in all of the analyses and the findings are presented in the publications, Chapter 5 to Chapter 9.

2.1.1.6 Bicycle mechanical failure

Bicycle mechanical failure including faulty brakes was identified in the literature a factor influencing crash involvement (National Coroners Information System, 2006). While it appears reasonable for cyclists to be responsible for the maintenance of their bicycle, it is possible that cyclists are not familiar with how to maintain their bicycle themselves or the frequency their bike needs to be serviced. Greater cyclist training about bike servicing and education about the implications of unsafe components may also be needed to reduce this contributing factor in cyclist-driver crashes.

However, bicycle mechanical failure is not a standard item reported in the literature from police or hospital data. It is not known how many cyclist-driver crashes occurred as a result of bicycle mechanical failure. This may be an important factor in preventing some cyclist-driver crashes and warrants further surveillance to determine the extent of this contributory factor; however, investigation of the issue was outside the scope of the current research program.

2.1.1.7 Low visibility at night (driver did not see cyclist)

In crashes that occur at low light times or at night, it is not surprising that low visibility of cyclists has been identified as a contributing factor for cyclist-driver crashes. Numerous studies have identified that in these conditions it is important for cyclists to use bike lights and reflective clothing to increase their visibility to other road users (Matthews & Boothby, 1980; Ballham, Absoud, Kotecha & Bodiwala, 1985; Hoque, 1990; Rowe et al., 1995; Osberg, Stiles & Asare, 1998; National Coroners Information System, 2006; Kim et al., 2007).

In Australia, it is mandatory at night or in hazardous weather conditions for cyclists to display a front white light and a rear red light – both need to be visible for at least 200m from the bike – and a rear red reflector (ARR 259) (Australian Transport Council, 2009). Cyclists are responsible for ensuring that they have adequate lighting and police can penalise riders for not having sufficient lighting. Interestingly, in France, bicycle retailers are also responsible for ensuring bicycles have adequate lighting. Bicycle retailers in France can be fined if they are found to be selling bicycles without lights (Osberg et al., 1998).

Despite the risks associated with riding without adequate lights at night, in Australia the majority of cyclist fatality crashes (83%) (Department of Infrastructure, 2010) occurred during daylight hours. This may be a function of exposure, as more cyclists ride during daylight hours. Given that the majority of cyclist fatality crashes in Australia occurred during the day, daytime travel was the focus of this doctoral research. Better understanding of cyclist crashes at night and the contributing factors is an important area for further research; however this was outside the scope of this study.

Of the seven cyclist-related factors that contribute to cyclist-driver crashes in this review of the literature, five were investigated in this doctoral research: did not see driver; disobeyed traffic control; error, misjudgement, inattention/ negligence; avoidance action; and gender. In the following section the driver-related factors that were identified in the literature as contributing to cyclist-driver crashes are discussed.

2.1.2 Driver contributory factors in cyclist-driver crashes

Six driver-related factors that contributed to cyclist-driver crashes were identified in this review. These were:

- did not see cyclist
- unprepared for cyclists on the road
- distracted/inattentive
- inappropriate overtaking manoeuvre
- non-compliance with traffic control
- inadequate indicator time

2.1.2.1 Did not see cyclist

Drivers' failure to see the cyclist has been identified in several analyses of cyclist-driver crashes in Australia (Australian Transport Safety Bureau, 2006; Schramm et al., 2008) and internationally (Rowe et al., 1995; McCarthy & Gilbert, 1996; Eilert-Petersson & Schelp, 1997). There has been considerable research conducted into drivers' looking behaviour and the visual search strategies drivers use (Summala, 1988; Koustanaï, Boloix, Van Elslande & Bastien, 2008).

Observational studies of driver looking behaviour at intersections in Finland were conducted by Summala, Räsänen and colleagues (Summala et al., 1996, Summala and Rasanen, 2000). Head movements of drivers as they approached an intersection were examined to identify strategies to increase the drivers' visual search patterns in the direction of the cyclists as they focused on the direction of the traffic to which they give way. It was hypothesised that drivers would give more attention to i) larger vehicles that are potential threats; and ii) traffic approaching from the left – in Australia this would be traffic approaching from the right. The rationale for this behaviour was that the traffic entering intersections from the *other* direction (in Australia this would be from the left) would be required to give way (to the target driver) and therefore it was thought that the drivers would check this direction less often and as a result, may fail to see vehicles from this direction, especially smaller vehicles such as cyclists. The authors found that speed reducing countermeasures, for example speed humps, were associated with greater visual scanning, as the drivers had more time on approach to the intersection to check traffic from both directions. Therefore, drivers would be more likely to see cyclists.

In Denmark, Herslund and Jørgensen (2003) used interviews and observations to investigate driver visual scanning behaviour at priority intersections. Many drivers who considered themselves to be good, careful drivers who looked for cyclists had been involved in a looked-but-failed-to-see near-collision. Drivers reported being very surprised and shocked at the presence of the cyclist. Interestingly, experienced drivers were more likely to be involved in looked-but-failed-to-see collisions with cyclists than inexperienced drivers. The authors noted that this was of concern because the behaviours of experienced drivers may be more difficult to address. They concluded that the looked-but-failed-to-see phenomenon cannot be explained by the physical environment such as a physical obstruction or obstacle, but rather is due to limitations in the driver's visual search strategy and/or their mental processing (Herslund & Jørgensen, 2003).

In France, Koustanaï, Boloix, Van Elslande and Bastien (2008) conducted an in-depth analysis of 77 crashes from the French National Institute for Transportation and Safety Research (INRETS) database of crashes for which the driver stated they had looked-but-failed-to-see. The authors concluded that there are two components to looked-but-failed-to-see crashes. First, the bicycle fails to attract a driver's attention. This, they proposed, is a perceptual failure in the first stage of the drivers' information processing. Second, it was proposed that drivers' failure to see may be due to incorrect interpretation of the cyclists' intention (Koustanaï et al., 2008). Consistent with Herslund and Jørgensen's (2003) findings, the authors also reported that this behaviour was more apparent in experienced drivers.

Despite the research finding that drivers' looking behaviour is central to looked-but-failed-to-see crashes, the main countermeasure recommended in Australia to reduce looked-but-failed-to-see crashes is for cyclists to increase their level of conspicuity to other road users (Australian Transport Safety Bureau, 2006). The inference being that it is the cyclist's responsibility to draw more attention to themself and in doing so, drivers will be more likely to see them. However, this recommendation fails to take into account the drivers' looking behaviour and assumes that a driver's cursory scan of the road environment would be, and should be, compensated for by cyclists' behaviour.

According to the literature, driver looking behaviour is a key contributing factor, particularly cyclist-driver crashes when the cyclist is travelling to the left of the drivers as drivers are less likely to check for (cyclist) traffic from that side. More research is needed to understand the role of driver looking behaviour in cyclist-driver crashes, to identify the circumstances that this driver behaviour contributes to crashes. In this doctoral research, drivers' looing behaviour was investigated in Stage 2 (see Chapter 8) and Stage 3 (see Chapter 9).

2.1.2.2 Unprepared to see cyclists on the road

Two studies identified that drivers may be unprepared to see cyclists and this contributed to cyclist-driver crashes, particularly in countries where cycling participation is relatively low. In a prospective study of 1,831 nonfatal cyclist crashes in the UK, Simpson and Mineiro (1992) reported that drivers' lack of preparedness to see cyclists on the road was a contributing factor. They reported that the other road user caused one-third of cyclist crashes, the most common crash type was cyclist struck from behind, especially when trying to turn right or while being overtaken. In Canada, a retrospective study of 212 cyclist fatality crashes, Rowe, Rowe and Bota (1995) reported that 43 per cent of adult fatality crashes were due to the driver failing to detect the cyclist. While clearly linked to looked-but-failed-to-see, the authors also associated this finding with low driver preparedness or expectation of cyclists on the road.

These two studies, conducted in the UK and Canada respectively, were conducted in countries with low cycling participation rates compared with European countries such as Denmark and the Netherlands. Therefore it might be expected that drivers in UK and Canada would be less prepared to see cyclists on the road. Given that bicycles are still a minority mode share in Australia, drivers' level of expectation of seeing cyclists may be a relevant factor for cyclist-driver crashes in this country. Driver preparedness to see cyclists on the road was not investigated directly in this doctoral research; however, the issue of drivers' awareness of cyclists as road users was explored indirectly using survey methods (see Chapter 6, Chapter 8 and Chapter 9).

2.1.2.3 Distraction/inattention

Driver distraction and inattention have been identified as factors generally for all crash types, but also in cyclist-driver crashes for almost three decades (Atkinson & Hurst, 1983); yet, as recently as 2009, these behaviours remain a factor in explaining cyclist-driver crashes (Schramm et al., 2008).

There is an extensive body of literature on crashes and driver distraction and inattention (Åberg & Rimmo, 1998; Klauer, Neale, Dingus, Ramsey & Sudweeks, 2005; Neale, Dingus, Klauer, Sudweeks & Goodman, 2005; Hatfield, Murphy, Job & Du, 2009; Sandin, 2009); however, little research has directly focused on the role of distraction and inattention in cyclist-driver crashes. Driver distraction/inattention is an important area of research and more needs to be understood about how driver distraction/inattention affects cyclist safety. However, this factor was outside the scope of this doctoral research and was not directly investigated in this research study.

2.1.2.4 Overtaking cyclists

Drivers overtaking cyclists was identified as a contributing factor in cyclist-driver crashes in this review (Walker, 2007). The primary concern is that drivers need to give sufficient space when overtaking cyclists. It is assumed that the greater distance drivers afford cyclists when overtaking, the safer the encounter is for cyclists.

Using a novel participant observation approach, Walker (2007) investigated the impact of cyclist gender, position on the road and other cyclist factors on drivers' overtaking behaviour. A hybrid bike was used, panniers were fitted with an ultrasonic distance sensor to measure the vehicles' overtaking distance. The cyclist/researcher rode through city streets dressed as a commuter/utilitarian cyclist in an androgynous-style shirt and trousers. He repeated the trips positioned at varying distances from the kerb, with and without a helmet and with and without a long wig so he appeared 'plausibly' to be female when seen by drivers from behind. Walker reported that drivers overtook him at distances ranging from 3.54m to less than 0m and he was struck twice. Walker concluded that overtaking drivers passed closer when he was a 'male' rider, wore a helmet and rode away from the curb. He concluded that cyclists' appearance is not a reliable basis on which drivers should base decisions about cyclist behaviour. Drivers need to be made aware of the fallibility of such assumptions (Walker, 2007).

Although not directly related to cyclist-driver crashes, an association has been made between safer cyclist-driver interactions and on-road bike lanes since the 1970s. In a quasi-naturalistic observational study, a series of photographs were taken of drivers overtaking a cyclist at midblock locations in Davis, California. Twenty sites in various speed zones were observed, half had bike lanes and half did not. At sites with bike lanes, drivers overtook cyclists with fewer swerving manoeuvres or close passes compared with sites without bike lanes (Kroll & Ramey, 1977).

Further investigation of bike lanes and driver overtaking behaviour was conducted by Harkey and Stewart (1997). The authors used a naturalistic study design to observe cyclists at 13 sites (10 urban, 3 rural). Based on observations of 1,583 driver-cyclist interactions, drivers were found to overtake cyclists with greater and more consistent clearance at sites with bike lanes compared with those without bike lanes. The authors also reported that cyclists were more likely to position themselves further away from the curb at sites with bike lanes than at sites without bike lanes. Further, the authors noted the importance of keeping bike lanes (particularly narrow ones) free of debris, in order to minimise the need for cyclists to swerve to avoid litter and risk riding into the path of a driver (Harkey & Stewart, 1997).

In Victoria, Australia, it is recommended that drivers provide 1m clearance when overtaking cyclists on the road (VicRoads, 2007). However, it is not known if this recommendation is widely known, or if providing 1m when overtaking is a typical practice among drivers in Australia. To address this gap in the knowledge, drivers' overtaking behaviour was investigated in this doctoral research in Stage 2 (see Chapter 8) and Stage 3 (see Chapter 9).

2.1.2.5 Non-compliance with traffic control

Driver non-compliance with traffic control, specifically at a stop sign or give way sign, was identified as contributing to cyclist-driver crashes. In their analysis of police crash records, Schramm and colleagues (2009) reported that 16.9 per cent of cyclist-driver crashes were attributed to driver non-compliance at a traffic control, including failure to yield at a give way sign (13%) and stop sign (3.9%).

Although driver compliance at all traffic controls is important for cyclist safety, investigating this behaviour was outside the scope of this doctoral research.

2.1.2.6 Inadequate indicator time

A case study by the Victorian coroner, included a description of a cyclist-truck fatality that, when deconstructed, identified that the driver's inadequate indication (signal) time was a contributing factor in the crash. Prior to the crash, a 25 year old, male cyclist was travelling downhill in the left lane at a fast speed (speed not specified) when a truck travelling in the centre lane indicated to turn across the cyclist's path, approximately 5m ahead of the rider. The coroner reported that the cyclist would have assumed that he was going to hit the truck, so he braked heavily. The heavy braking caused his back wheel to lock, he skidded over 16m before losing his balance, was flung over the handlebars and hit the truck. The cyclist sustained extensive injuries to his head and shoulders. The truck driver had no knowledge of the collision and continued driving 'consequently running over the deceased with his rear tyres' (p5). An inspection of the bike found the brakes were 'poor'. The coroner recommended modifications to the truck (side guards) and suggested that had the cyclist properly maintained his bicycle he may have avoided the outcome. The coroner's recommendation placed responsibility for avoiding the crash with the cyclist, offering vehicle modification as a preventive measure (National Coroners Information System, 2006).

However, careful deconstruction of this event reveals that the driver's responsibility was greater than attributed by the coroner. The catalyst for the event was the truck driver indicating to turn left across the cyclist's path, the cyclist then braked heavily. While it is possible that with better maintained brakes the cyclist may have stopped before the collision, the fact that heavily braking was required suggests that the driver did not provide adequate indication time for the cyclist to safely adjust his speed or change direction.

In addition, as evidenced by the driver's action in running over the cyclist, it was clear that the driver did not see the cyclist and was completely unaware of his presence. This may suggest that the driver did not look for the cyclist, although it is also possible that the cyclist was riding in the truck driver's blind spot. This could not be determined from the data provided in the coroner's report.

Lack of indicator time can directly impact cyclist safety as cyclists rely on adequate warning from drivers to anticipate their change in direction. Yet there has been little attention given to this driver behaviour in the literature. Drivers' indication time prior to turning was investigated in this doctoral research in Stage 2 (see Chapter 8) and Stage 3 (see Chapter 9).

Of the six driver-related factors that contribute to cyclist-driver crashes in this review of the literature, four were investigated in this doctoral research: did not see cyclist; unprepared for cyclists on the road; inappropriate overtaking behaviour; and inadequate indicator time.

2.1.3 Road and road environment contributory factors in cyclist-driver crashes

The review identified two road-related contributory factors for cyclist-driver crashes: vehicle speed (Stone & Broughton, 2003; de Lapparent, 2005; Richter et al., 2007) and road surface (Atkinson & Hurst, 1983). In addition, numerous studies identified that cycling-inclusive road design was important to reduce cyclist-driver facilities, so literature on the most common on-road cycling facilities, bike lanes and bike boxes, is also discussed in this section (McClintock & Cleary, 1996; Harkey & Stewart, 1997; Moritz, 1997; Daff & Barton, 2005; Pucher, Dill & Handy, 2010).

2.1.3.1 Vehicle speed limits

Several studies have identified vehicle speed as a significant road-related contributing factor in cyclist-driver crashes. In a review of police data for cyclist-driver crashes from 1990 to 1999, Stone and Broughton reported three-quarters of cyclist fatal and nonfatal crashes occurred on roads with speed limits of 30mph (48 km/h) but that fatality rates increased markedly with speed limits (Stone & Broughton, 2003). In France, a review of 918 cyclist fatal and nonfatal crashes reported that speed was a significant factor, especially in dry and clear weather conditions. In such conditions, drivers are likely to travel at higher speeds that in inclement weather conditions (de Lapparent, 2005).

Researchers have demonstrated that 30km/h is the maximum for human injury tolerance for an unprotected road user (Tingvall & Haworth, 1999; Corben, Logan & Oxley, 2008) (see Figure 2-1).

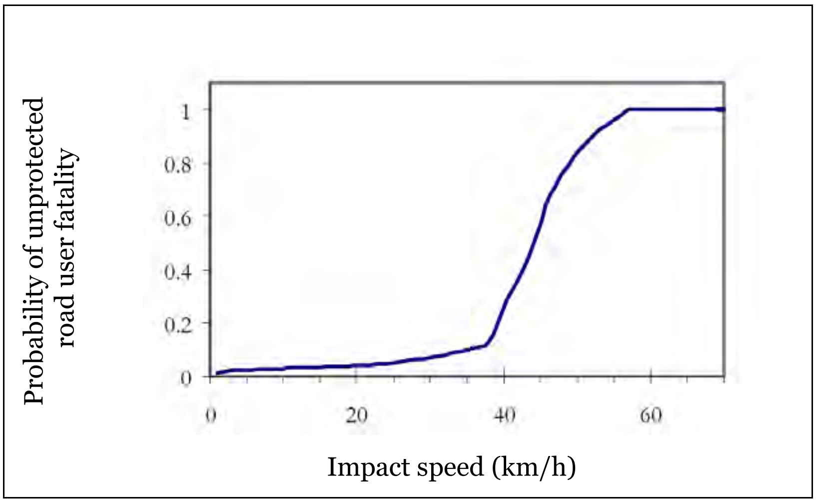

Figure 2-1 Relationship between probability of an unprotected road user fatality and impact speed
Adapted from (Corben et al., 2008)

In countries with high cycling participation, a 30km/h speed limit has been widely implemented in urban and residential areas (Herrstedt, 1992; Vis, Dijkstra & Slop, 1992). Given that according to the data in Figure 2-1, a crash with a vehicle travelling at 50km/h is likely to result in a fatality for unprotected road users, it is of concern that in a recent study of Australian drivers, most (71.8%) reported that they considered 50km/h was 'about right' for driving in residential areas (Lahausse, van Nes, Fildes & Keall, 2010:6).

The majority of cyclist fatality and serious injury crashes occurred in speed zones of up to 70-75km/h (Henley & Harrison, 2009; Department of Infrastructure, 2010). Therefore the observation sites for the Stage 1 and 2 observational studies were located in speed zones within these limits.

2.1.3.2 Road surface

Road surface, in particular the need for cyclists to manoeuvre around a surface defect or debris, was identified in the cyclist-driver crash literature review as a contributing factor. Atkinson and Hurst (1983) analysed police reported cyclist crashes (550 non fatal and 142 fatal crashes) that occurred in New Zealand between 1973 and 1978. The authors reported that the most common pre-crash behaviour in all cyclist crashes was the cyclist unexpectedly or unintentionally swerving into the path of a driver. The authors suggested that poor road surface may be a reason for this cyclist behaviour. In a prospective study of cyclist crashes in the UK from January 1982 to May 1985, Simpson and Mineiro (1992) reported that environmental factors were contributory in 78 crashes. Of these crashes, 15 (19%) were due to hazards created by the road surface, mainly potholes.

These studies are both somewhat dated and it is not known if or how the road surface in metropolitan areas of Melbourne may be affecting cyclist behaviours or contributing to cyclist-driver crashes. Recent data on road surface for Australian crashes was not found in this review of the literature. Road surface was included as a variable in Stage 2 of this doctoral research (Chapter 8).

2.1.3.3 Road design

In the review of the literature, researchers repeatedly highlighted the need for cyclist-inclusive road design to improve cyclist safety (de Lapparent, 2005; Haileyesus et al., 2007; Schramm et al., 2008). In Australia, the main effort to improve cyclist safety on the roads has been to provide designated spaces for cyclists by implementing cycling-related facilities and infrastructure. The intention of allocating on-road space to cyclists is to create a 'clearly defined and dedicated space that separates [cyclists] from adjacent motor vehicles. This separation is thought to increase cyclists' safety, improves traffic flow and can improve the performance of the road' (VicRoads, 2001).

Given that these facilities have been the primary cyclist safety measure undertaken to date in Australia, it was important to better understand if these facilities were contributing or reducing cyclist-driver crashes and effectively providing a safe space for cyclists. The two most common on-road cycling facilities were investigated in this doctoral research: bike lanes and bike boxes. A brief review of literature related to these facilities is below.

On-road bike lanes

In Australia and internationally, bike lanes are the most frequently implemented on-road cycling facility. Bike lanes are typically a white painted line with an occasional bicycle symbol stencilled on the road within the lane (see Figure 2-2).

Figure 2-2 Standard bike lane

Bike lanes were first used on Melbourne roads in the early 1980s for the purpose of 'reducing the stress of cyclists' (Daff & Barton, 2005:1). It was reported that both cyclists and drivers preferred roads with bike lanes when sharing the road, understood the purpose of the cycling-related line markings and were highly compliant (Daff & Barton, 2005).

Similar driver and cyclist reactions have been reported internationally. Drivers have reported feeling more confident when there are bike lanes marked on the road (Basford, Reid, Lester, Thomson & Tolmie, 2002; Daff & Barton, 2005) and cyclists have reported increased feelings of safety with designated lanes (Harkey & Stewart, 1997; Moritz, 1997; Daff & Barton, 2005).

National and state guidelines provide specifications for bike lane width and on road placement (Austroads, 1999; VicRoads, 2005). The minimum bike lane width varies and is dependent on the speed zone (1m in <60km/h zones, 1.5m in 60km/h zones, 2m in 80km/h zones, 3m in 100km/h zones or where cyclist demand is heavy) (Austroads, 1999). Occasionally sections of the bike lane are painted green, usually at complex locations, to highlight the presence of the bicycle lane to drivers (see Figure 2-3) (VicRoads, 2005).

Figure 2-3 Green painted bike lane

Bike lanes are typically positioned along the left of the left-most vehicular lane, either alongside the curb or parking bays. However, there are risks related to the on-road bike path placement. Where space is limited, bike lanes are considerably narrower than specified in the guidelines. Typically at squeeze points on the road where there is insufficient space for both vehicles and bicycles, the bike lane will end leaving the cyclist to 'defend their position' (Austroads, 1999:244) on the road with the vehicular traffic.

The role of bike lanes in cyclist safety was investigated in this doctoral research. The absence or presence of bike lanes at the sites of cyclist-driver collisions or near collisions were analysed in Stage 2 (Chapter 8). Driver and cyclist knowledge of road rules related to bike lanes and attitudes towards sharing the road with cyclists on road with and without bike lanes were explored in Stage 3 (Chapter 9).

Bike boxes

The bike box, also known as the advanced stop lane, head start area or bicycle storage box, is a cycling facility that originated in the Netherlands and has been widely implemented in European countries and is increasingly implemented in the US, Canada and the UK (Pucher et al., 2010). The box provides a space ahead of the vehicular traffic for cyclists to wait at during the red light phase (see Figure 2-4). Bike boxes have been widely implemented at signalised intersections in Melbourne.

Figure 2-4 Bike box

Bike boxes allow cyclists to be positioned ahead of the waiting traffic and cyclist safety is considered to be enhanced due to two factors: i) conspicuity: drivers are more likely to see them, and ii) advanced start: when the light changes to green, the cyclist can ride off ahead of the traffic and safely gain their momentum (McClintock & Cleary, 1996; Hunter, 2000; VicRoads, 2000; Wall, Davies & Crabtree, 2003; Daff & Barton, 2005; Pucher et al., 2010). In addition, in front of the traffic, cyclists do not have to inhale the exhaust fumes from the stationary vehicles. In Victoria, the guidelines recommend the bike box be placed in front of the left-most traffic lane, unless it is a left turn only lane, in which case the box should be in front of the left through lane, clear of the turning vehicles (VicRoads, 2000).

For the bike boxes to effectively create a safe space for cyclists on the road, both cyclists and drivers need to be compliant. Daff and Barton (2005) reviewed seven studies that investigated the effects of on-road cycling treatments in Melbourne and reported that at bike boxes, observed driver behaviour was compliant, as the majority (67%) of drivers stopped behind the bike box.

Research in New Zealand found that driver encroachment into the bike box negatively influenced cyclist confidence and their position at the intersection.

Although there was a reduction in cyclist-driver crashes after the installation of the box and cyclists reported feeling safer, drivers did not like cyclists being positioned in front of them and reported that they felt unsure or non-committal about the purpose and function of the bike box (Newman, 2002). In a before-after observational study in the US, Hunter (2000) found that more than half the drivers observed (51.9%) encroached into the bike box (Hunter, 2000). In the United Kingdom, of 5,114 cyclists observed, a vehicle encroached into the bike box while a cyclist was waiting for over a third (36%) of the cyclists observed (Allen, Bygrave & Harper, 2005).

The intention for on-road cycling facilities is improved cyclist safety. However, researchers have concluded that cycling facilities alone are not likely to increase cycling rates (Dill & Carr, 2003; Pucher et al., 2010). In this doctoral research the behaviours of cyclists and drivers at bike boxes was investigated in Stage 1 to determine if bike boxes do create a safe space for cyclists (see Chapter 6). Further, in Stage 3, drivers' and cyclists' understanding of the road rules related to bike boxes was investigated.

Both of the two road-related factors that contribute to cyclist-driver crashes in this review, speed and road surface, were investigated in this doctoral research. In addition, behaviour, knowledge and attitude related to two on-road cycling facilities, bike lanes and bike boxes, were also investigated in this study.

2.1.4 Vehicle contributory factors in cyclist-driver crashes

One vehicle-related contributory factor was identified in the analysis of cyclist-driver crash literature. Truck design was identified in a case study of a cyclist-truck fatality crash, a described in Section 2.1.2.6 above (National Coroners Information System, 2006). The coroner recommended side guards to the truck to protect cyclists from this type of crash. Vehicle design that is inclusive of non-occupant road users, particularly physically vulnerable road users, is an important area of cyclist safety research. However, vehicle design was outside the scope of the research and was not investigated in this doctoral research.

2.1.5 Other contributory factors in cyclist-driver crashes

Inclement weather was correlated with an increase in injury severity outcome (Kim et al., 2007). Kim and colleagues proposed that wet roads are suboptimal for drivers' braking and steering which in turn leads to greater impact speeds and greater injury outcomes. It is likely that there are a range of weather-dependent factors that influence the occurrence of crashes and the severity of injury outcomes, however as discussed in Chapter 1, the majority of crashes in Australia occur in dry and clear weather conditions and these conditions were the focus in this doctoral research. The role of inclement weather in cyclist safety was outside the scope of the current research.

Summary

In summary, the aim of this chapter was to identify the major contributing factors in cyclist-driver crashes. To achieve this aim the literature on cyclist-driver crash data was reviewed. Nineteen key articles were identified and reviewed and five main groups of contributing factors were discussed: cyclists, drivers, roads, vehicles and other factors.

Five cyclist-related factors were identified in the literature as contributing to cyclist-driver crashes and were investigated in this doctoral research. Cyclists' looking behaviour was investigated as although cyclist failure to see had been reported to be a factor in a third of cyclist fatality crashes, no research was found that directly investigated cyclist looking behaviour in relation to crashes. Cyclists' behaviour at red lights was also investigated. Although cyclist red light infringement was reported to be a factor in only a small number of crashes, previous literature did not provide denominator data to determine the extent of infringement behaviour or the affect on cyclist safety. Previous research reported cyclist error and avoidance behaviour as contributing factors in cyclist-driver crashes, however in this doctoral research, the broader circumstances that may provide reasons for these behaviours were also explored. Finally, cyclists' gender was a factor in cyclist-driver crashes, primarily as males were over-represented in crashes. Gender was included in the analysis to determine its role in cyclist and driver behaviour, knowledge and attitudes.

Four driver-related factors were identified in the literature as contributing to cyclist-driver crashes and were investigated in this doctoral research. Drivers' looking behaviour and being unprepared to see cyclists were determined to be contributing factors and were included in the analysis collisions and near-collisions. In the literature, drivers' overtaking behaviour was identified as a contributing factor, however little was known about the extent of drivers' behaviour in crashes or drivers' knowledge of appropriate overtaking behaviour. In this doctoral research, drivers' observed and self-reported overtaking behaviour was investigated. Finally driver indication time prior to turning was identified in the review of the literature, however no studies were found that directly investigated this driver behaviour. In this study, driver indication time, both observed and self-reported were explored.

Two road-related factors that were identified in the literature as contributing to cyclist-driver crashes were included in this doctoral research. Given the role of speed limits in cyclist-driver crashes, speed was an inclusion criterion in the selection of observation sites, however actual travel speeds were not investigated. Road surface was included in the analysis of observed collisions and near-collisions. In addition, the two most common on-road cycling facilities, bike lanes and bike boxes, were explored in terms of cyclist and driver behaviour and knowledge of the road rules related to the facilities.

Following this literature review, the research questions for this doctoral research were determined. The research questions were developed to direct the research and to ensure that the contributory factors identified in the literature review were systematically investigated. However, it was also recognised that all the contributory factors in cyclist-driver crashes were unlikely to have been identified in the previous research. The research questions were also developed to ensure there was space to identify new factors that were important to cyclist safety.

2.2 Research questions

Four research questions were developed to direct this doctoral research. These were:

1. *What are the behaviours and characteristics of road users that place cyclists at risk?*
2. *What is the role of cycling infrastructure/facilities in cyclist-driver interaction and behaviour?*
3. *What contributing factors can be identified in cyclist-driver collision and near collision events?*

4. *How does driver knowledge and attitude influence their behaviour in relation to cyclist safety?*

These questions were addressed in the three stages of research that were conducted and collectively addressed the study aim of identifying characteristics of the road users and road system that contribute to cyclist crash risk.

This concludes the formal literature review chapter; however, as discussed above, reviews of the relevant literature are included in the publications in Chapters 5 to 9. In the next chapter, the theoretical framework and research design for this doctoral research are presented.

Chapter 3
Theoretical framework and methodological approach

In this chapter, the theoretical framework, methodological approach and the rationale for their selection in this doctoral research is provided. The chapter is structured in three main sections as outlined below.

First is an overview of the background of the science of an injury prevention approach to safety. Particular emphasis was given to the shift in focus from the concept of 'accident' to 'injury' and the systematic approach to reducing injurious events. Second is a description of the theoretical framework that was applied, the Safe System Framework (SSF). The version of the SSF discussed is from the current Victorian Road Safety Strategy, *arrive alive 2008-2017*. Third is a detailed description of the research methodology used; this includes: the research paradigm, study design, rationale for the commuter cyclist focus, research matrix and ethical considerations.

3.1 Defining the science of injury prevention

Historically, events that resulted in an injury were called 'accidents' (Yan-Hong et al., 2006). The implication was that the injured individual was responsible for the event and shared the guilt for their own injury (Guarnieri, 1992). For example, industrial incident records from the 19th century and early 20th century reported that 'more than 90% of the time the employee was at fault; and the remaining cases were unpreventable *acts of God'* (Guarnieri, 1992:152).

The need for a more systematic, scientific understanding of injuries emerged in World War II, where thousands of men were injured, resulting in considerable loss of man power (Gordon, 1949). Gordon was the first to recognise the need for a systematic, scientific understanding of injuries and reconceptualised the traditional notion of an accident by applying the epidemiological structure of disease causation. Specifically, he rejected the notion that there was a singular cause of an accident, that is, that the injured person was to blame. Instead, he identified three sources: 1) the host or person involved (e.g. characteristics such as age, gender, race); 2) the agent (e.g. available energy, either mechanical, thermal, chemical), and; 3) the environment (e.g. physical and/or social context within which the injury event, its precursors, and consequences occur). His primary argument was that all three factors were fundamental in causation, were intimately interwoven and were influenced by each other. A balance of all three factors resulted in health, while an imbalance or disturbance of the equilibrium was the cause or basis of disease.

Moreover, Gordon detailed key factors to be considered for each of the three causal factors. With respect to the host, the person's age, gender and race were considered. In addition, in 1949, the psychological condition of 'genetic inherent susceptibility' was considered important. Genetic inherent susceptibility referred to how accident prone a person was, as it was considered that psychological differences in some people resulted in them experiencing more accidents than others. For the agent, Gordon was less specific, stating that 'Information about the agents concerned in accidents is none too satisfying because of the common failure to distinguish mechanism from actual agent' (p509). Environmental sources of injury causation were also proposed including physical, biologic and socio-economic elements.

The next major shift in terms of defining the science of injury prevention came in the early 1960's when both Gibson (1961) and Haddon (1963) rejected the word 'accident' and its 'hodge podge of legal, medical, and statistical overtones' (Gibson, 1961 cited in Guarnieri, 1992: 153), and focused more on the causes of injury. By this time, the psychological component of the host, the genetic inherent susceptibility had been discarded (Guarnieri, 1992). Expanding Gordon's notion of accident causation factors, Haddon provided a more specific description of the agent. The agent must involve a transference of energy '…in such ways and amounts, and at such rates, that inanimate or animate structure are damaged' (Haddon, 1963).

In his landmark paper in 1968, Haddon presented a matrix for identifying major components of an injury. The three stage matrix conceptualised an injurious event and included examples in the road safety context:

1. *pre-event:* this stage relates to the prevention of crashes. The aim of this stage is to prevent mechanical forces from reaching vehicles or people. In road safety, this stage primarily focused on compliant road user behaviour, however it also related to appropriate speed limits, the physical road environment and vehicle design

2. *event:* this stage relates to when a crash has occurred and the forces have reached the individual. The objective is to minimise physical injuries through some protective mechanism. Haddon referred to the need for effective 'packaging of human cargo' (p1435) to minimise injury. An example for cyclists is use of a bicycle helmet to minimise the severity of a head injury in a crash involving a head strike. For drivers, examples include the use of seat belts and the inclusion of internal airbags in vehicles

3. *post-event:* this stage relates to reducing the likelihood of death and serious injury by optimising the timing and sequence of emergency medical services and rehabilitative care. Haddon referred to this stage as 'maximising salvage' (p1435)

Haddon's original concept for understanding contributing factors for crash causation and injury (1968) was refined in 1972. Social aspects of the environmental circumstances relating to the event were added to the matrix (see Table 3-1) (Haddon, 1972). A benefit of the matrix is that it facilitates an interdisciplinary approach to an issue by identifying a range of potential risk and protection factors across the various time phases (Runyan, 2003).

Table 3-1 Haddon's matrix

		Human/ Host	Agent/ Vehicle	Physical environment	Social environment
Time ↓	Pre-crash – crash prevention				
	Crash – minimising injury severity				
	Post-crash – minimising affect after a crash				

In addition to the matrix, Haddon also developed countermeasures for injury prevention. The countermeasures, initially four which were later expanded to ten, were classified to address the reduction of human and economic loss (Haddon, 1970; Runyan, 2003):

1. prevent the creation of the hazard
2. reduce the amount of hazard brought into being
3. prevent the release of the hazard
4. modify the rate of release of the hazard from its source
5. separate the hazard from that which is to be protected by time and space
6. separate the hazard from that which is to be protected by a physical barrier
7. modify relevant basic qualities of the hazard
8. make what is to be protected more resistant to damage from the hazard
9. begin to counter damage done by the hazard
10. stabilise, repair and rehabilitate the object of damage

Central to Haddon's approach was the recognition that humans would make mistakes but that fatality is too high a penalty to pay for being human (Guarnieri, 1992).

Similar to Haddon's systematic approach to injury prevention, Rasmussen and later Reason developed and refined a systems approach to incident prevention within the risk management domain. The systems approach, originally used in aviation and nuclear power safety, acknowledged that there were many components to a system that contained barriers and safeguards to prevent an injurious event (Rasmussen, 1982; Reason, 1990; Rasmussen, 1997; Reason, 2000). It is argued that the occurrence of injurious event represents a failing of the system at multiple points. The theory is simplified in Reason's 'Swiss cheese' model (see Figure 3-1) that maps the trajectory of an event through the 'gaps' in the safeguards and barriers that allowed the event to occur.

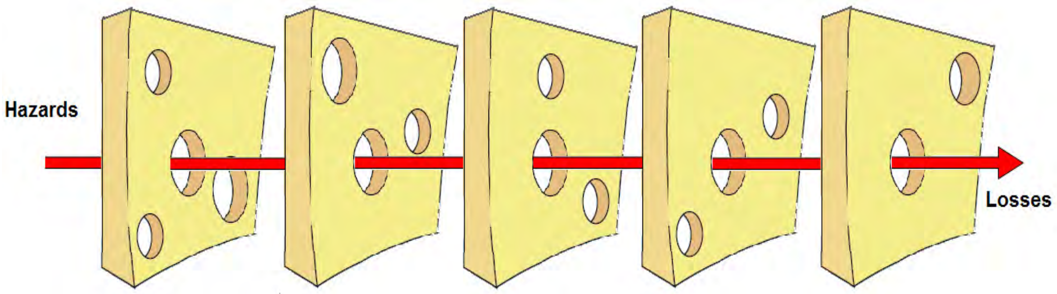

Figure 3-1 The Swiss Cheese Model
Adapted from Reason, 2000: 768

The systems approach developed by Rasmussen and Reason included a detailed account of the operational components in analysing injurious events. Rasmussen used the Zeebrugge ferry disaster in Belgium in 1987 to illustrate the systems approach. He identified that several decision makers at different times all contributed to the eventual disaster (Rasmussen, 1997). In this event, the bow doors of the ferry were not closed by the Assistant Boatswain, who had been asleep in his bunk. As the ferry moved into the harbour, the bow filled with water, eventually capsized and 193 people were drowned (Pijnenburg & Van Duin, 1990). While the failure to close the doors was a contributing factor, there were additional points or barriers in the system including vessel design, harbour design, personnel management and vessel operation that had failed before the ultimate error.

As with Haddon's matrix, the systems approach takes a broad view to identify and address all contributing factors in order to create a safe environment. The approach represented a shift from addressing only the responsibilities of the individual road user or 'person approach' (Reason, 2000) to addressing the contribution of the entire system. Despite the widespread use of Haddon's matrix in injury prevention, particularly addressing road injuries (Guarnieri, 1992; Runyan, 1998, 2003; Barnett, Balicer, Blodgett, Fews, Parker et al., 2005; Eddleston, Buckley, Gunnell, Dawson & Konradsen, 2006) and Rasmussen's and Reason's system approach in risk management and human factors research (Noyes, 1998; Marais, Dulac & Leveson, 2004; Leveson, 2011), the Road User Approach persisted in road safety with continued emphasis on behavioural intervention (Larsson, Dekker & Tingvall, 2010).

3.1.1 Road safety

As noted above, traditional road safety strategies emphasised the individual road user as the primary agent and therefore the key mechanism to improve safety was improved road user behaviour. Implicit in this approach was the assumption that the road system was adequate and that 'accidents' occurred as a result of poor behaviour, either a violation or an error. For the most part, this approach ignored the role of other system factors such as other road users and the design and operation of the road (Tingvall, 1998; Larsson et al., 2010). The Road User Approach also accepted that to engage in the road network, meant there would be an accepted proportion of deaths and serious injuries, as implicit in the term 'road toll'.

The first, formal shift away from the road user approach in road safety to a systematic theoretically based approach in the 1990's when it was first articulated in policy form in the Dutch Sustainable Safety and the Swedish Vision Zero approaches.

The Dutch Sustainable Safety approach was implemented in 1992 and the policy restructured the approach to road safety. Human life was central in the policy and the emphasis shifted to a need to adapt roads, vehicles and driving tasks to accommodate human limitations (Van Loon, 2001). The Sustainable Safety approach was originally based on three safety principles: functionality of roads; homogeneity of mass and/or speed and direction; and predictability of road course and road user behaviour by recognisable road design. In the second phase of its implementation, two additional safety principles were added to the Sustainable Safety approach: state of awareness by the road user, and; provision of a more forgiving environment for road users (Wegman, Aarts & Bax, 2008). In this approach it is acknowledged that road collisions can be avoided, but if they do occur, serious injury will be avoided (Wesemann, Norden & Stipdonk, 2010).

The Swedish road safety strategy, Vision Zero was introduced in 1997 and with clear deference to Haddon's work (1968), the Vision Zero strategy rejected the tolerance of deaths and serious injuries and stated that it was unacceptable for road users who make mistakes to be punished by fatal or severe outcomes (Swedish Road Administration, 2006). Vision Zero also incorporated Rasmussen and Reason's system approach and acknowledged that 'responsibility for safety is shared between those who design and those who use the road transport system' (p2). Individual road users must be knowledgeable and comply with all the road rules, but more emphasis was placed on the system designers, as it was argued that they are ultimately responsible for providing a safe transport system in which users can operate safely. These system designers include road managers, vehicle manufacturers, politicians and the police.

It is against these backgrounds that the Safe System Framework was developed. The Framework forms the basis for current road safety policy and practice across Australasia and is the context in which the doctoral research was implemented.

3.2 Safe System Framework

In Australia, there were substantial reductions in road trauma from 1970 when the fatality rate was 30.4 per 100,000 population to 2000 when the rate had decreased to 9.5 per 100,000 population (Australian Transport Safety Bureau, 2008). While major gains were made, there was a slowing of these gains in the early 2000s and new and innovative ways were sought to achieve further reductions in road trauma. The Safe System Framework (SSF) was therefore adopted by Austroads and the Australian Transport Ministers in 2004 and the SSF principles are at the core of the current 10-year National Road Safety Strategy (2011 to 2020) (National Road Safety Council, 2010). The SSF is a systems approach to road safety and underpins road safety strategies Australia-wide, with each jurisdiction developing a version to meet the jurisdictional priorities. The four main tenets are: safer road users; safer roads and roadsides; safer vehicles, and; safer speeds (Langford, 2005).

The version of the SSF used in this doctoral research was from the current Victorian Road Safety Strategy, as the research was primarily conducted in Victoria. The Victorian SSF approach is discussed in the next section with particular emphasis on the implications for cyclist safety.

3.2.1 Road safety policy in Victoria

The research presented in this thesis was anchored in the road safety policy context in the state of Victoria. The model currently in use in Victoria (see Figure 3-2) forms the theoretical basis for the Victoria Road Safety Strategy, *arrive alive 2008-2017*.

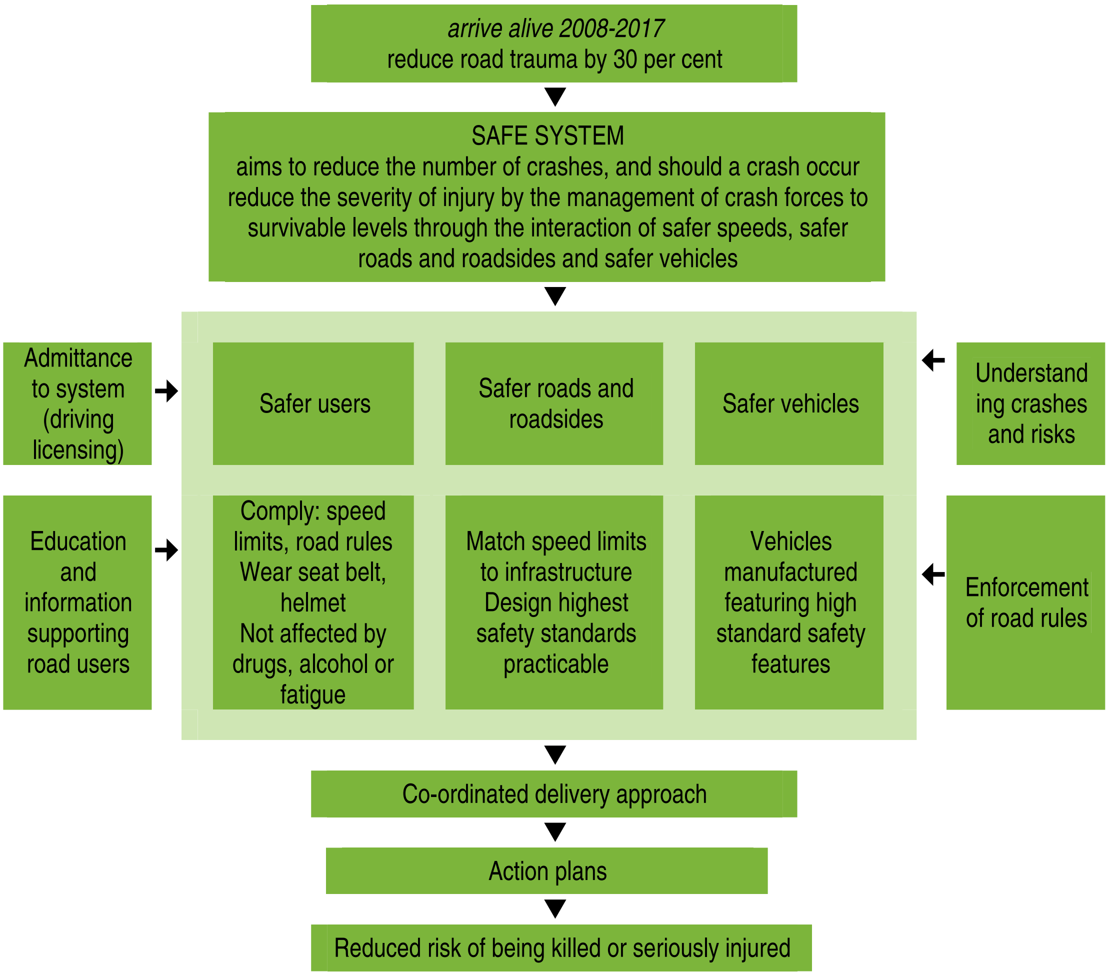

Figure 3-2 The Safe System framework
Adapted from VicRoads, 2008: 13

The overarching aim of the Strategy is to reduce road trauma by 30 per cent. The Safe System is established in the second tier of the framework and it is clearly stated that should a crash occur, injury severity should be minimised.

Importantly, this Safe System tier focuses on speeds, roads and roadsides and vehicles. Road users are not listed here. Instead, road users are included on the third tier as one of the factors in the broader road safety picture. This model represents an important shift away from the Road User Approach.

Consistent with the broad safe system approach, in the Victorian road safety strategy three critical components were identified for improved cyclist safety: lower vehicle speeds, safer vehicles and infrastructure. Each of the components and the proposed action are discussed below.

Lower vehicle speeds: It is clearly stated in the Strategy that a cyclist struck by a vehicle travelling in excess of 40km/h is not likely to survive. As discussed in Chapter 2 for physically unprotected road users, a fatality outcome is likely at speeds in excess of 30km/h (Corben et al., 2008). Lowering speed limits is a tangible and effective system change that would yield positive results for cyclists (as well as all road users), particularly in residential areas (Vis et al., 1992). The recommendation in the Strategy is that speed limits should be set in accordance with safety standards in areas with high cyclist activity (VicRoads, 2008b: 43).

Despite the acknowledgement of high fatality risk of cyclists and other vulnerable road users at speeds in excess of 30km/h, the current default urban speed limit is 50km/h. Although 40km/h speed zones have been applied in suburban shopping strips and timed zones around schools, there has not been widespread lowering of speed limits to specifically address safety. Along many of the most used on-road cyclist commuter routes to the Melbourne CBD, the speed limit remains at 60km/h. As the strategy is current until 2017, there may still be action to reduce speed limits along routes used by large numbers of cyclists, however, at the present time, there is no known plan to reduce the speed limit along major on-road cyclist routes in Melbourne or Victoria.

Safer vehicles: This component relates specifically to the need for a less aggressive vehicle fleet. Vehicle mass and design are significant factors in the severity of injuries sustained by a cyclist in a collision (Richter, Pape, Otte & Krettek, 2005; Watson & Cameron, 2006). For instance, a cyclist struck by a van or a four wheel drive with a high bumper is much more likely to incur serious head injuries than when struck by the bonnet (hood) of a passenger car (Watson & Cameron, 2006).

To address this issue, it is stated in the Strategy that consumer awareness campaigns would be conducted to discourage the purchase of large, aggressive vehicles. Currently, there is no evidence of this action; indeed according to vehicle sales the opposite trend is apparent. The Federal Chamber of Automotive Industries' latest report concluded that the four wheel drive or SUV (Sports Utility Vehicle) segment was 'the strongest performer during August (2010), recording an increase of 32.5 per cent' compared to sales in August 2009 (Federal Chamber of Automotive Industries, 2010). Moreover, there is little mention made in the Victoria Road Safety Strategy of how the government may work with the vehicle manufacturing industry to improve safety of these vehicles for vulnerable road users. Such a partnership could develop criteria for cyclist-inclusive safety tests in Australasian New Car Assessment Program (ANCAP) testing and promote the inclusion of safety features in vehicles as high-value components.

Infrastructure: The critical infrastructure issue identified in the Strategy was the need for greater vehicle-bicycle segregation. In the Strategy it is stated that '... providing vehicle-free paths and facilities for cyclists is an extremely effective way of improving their safety' (VicRoads, 2008b: 43). This broad issue statement reflects a fundamental premise that the safest place for cyclists is off the road. Such a statement poses an apparent juxtaposition with the current road law which sanctions cyclists as legitimate road users.

However, in the detail of the measures to be taken, there is a clear intention in the Strategy for there to be more bicycle-inclusive facilities/infrastructure in the road network. Planned actions include improvement to existing roads and bicycle-inclusive town planning. Increased off-road paths and facilities are included, but only as part of a wider range of measures – rather than the sole solution. The apparent contradictions in the Strategy may be reflective of a greater confusion about the role of bicycles as a mode of transport in Australia and on Australian roads.

The critical components for cyclist safety identified in the Victorian road safety strategy represent a welcome inclusion of some broad system factors. However, three years into the strategy, there is little evidence of any cyclist-related speed reductions (particularly on regular commuter routes) or initiatives to reduce vehicle fleet aggressivity. While there have been some additional segregated bike lanes installed in sections of roads in inner suburbs of

Melbourne, there is little clarity on the position of cyclists on the road. Further, the provision of segregated paths may undermine the perceived legitimacy of cyclists as road users. In addition, there is a notable omission in the strategy: the role of the driver in cyclist safety. Of eight measures listed for improving cyclist safety, only one relates to drivers:

- improving compliance with road rules by all motorised and non-motorised road users using enforcement and education (VicRoads, 2008b:42)

This measure acknowledges that all road users need to comply with the road rules, a key tenet of the Safe System framework. Although there is mention throughout the policy of the need for safer driver behaviour, the main focus is on reducing speeding, driver distraction, drink and drug driving and fatigue. There is no specific call for changes in driver behaviour in relation to cyclists, which may lead to the inappropriate assumption that no further driver behaviour change would be necessary to improve cyclist safety.

In contrast, a specific measure is included in the Strategy for cyclists:

- review the existing legislation to ensure that cyclists can be charged with serious traffic offences similar to those applied to drivers (VicRoads, 2008b:43)

The recommendation reinforces the notion that cyclists' behaviour is aberrant and requires directed improvement while drivers' behaviour does not. The neglect of driver behaviour is significant given the numerous driver-related contributing factors that have been identified in the cyclist-driver crashes, as discussed in Chapter 2. The role of driver behaviour in cyclist safety is a key component of this doctoral research and is explored further in Chapters 6 to 9.

While the need for a systems approach is recognised in Victoria with the inclusion of the SSF in the road safety strategy, the *actions* outlined in the strategy suggest that perhaps there are remnants of the road user approach remaining, particularly in relation to cyclists. Indeed the review of the Victorian road safety strategy highlighted that, from a cyclist safety perspective, there persists a driver-centric approach.

It is acknowledged that all components of the SSF are important to improving cyclist safety, however it was not feasible to explore all components in a meaningful way in this doctoral research. As discussed in Chapter 2, the main focus of this doctoral research was cyclists and drivers and roads.

In summary, the science of injury prevention has shifted the focus from person-based to systems-based and a broader systems approach has been adopted to ensure that all contributing factors and their interactions are considered in understanding crashes and crash risks. While efforts towards a system approach have been made in theory in Australia, more is needed to truly achieve a system approach when it comes to cyclists and their safety. In this doctoral research, the SSF main components of interest are safer road users and safer roads and roadsides. The research approach is discussed in the next section.

3.3 Research method

This research method section is presented in five parts. The first section outlines the research paradigm and includes a description of the ideological framework for the research. In the second section, the research design is presented, including an overview of the three stages of the research program. Next, a rationale is outlined for the focus on commuter cyclists and a research matrix is presented to summarise how each of the research questions addressed specific components of the Safe System Framework. Finally, the ethics approval process and specific ethical considerations for the studies is described.

3.3.1 Research paradigm

This doctoral research was exploratory to enable a broad investigation of key factors that may impact the safety of on-road cyclists. Given the complexities of contributing factors to crash and injury risk, a mixed method approach, rather than a single mono-method approach was considered to be most appropriate to address these issue comprehensively (Johnson & Onwuegbuzie, 2004).

Taken from sociology, social research and educational research perspectives, the mixed model, or ‘third paradigm’ (Johnson & Onwuegbuzie, 2004) is positioned within a pragmatic philosophical perspective and rejects a forced choice between a qualitative or quantitative paradigm (see Figure 3-3) (Howe, 1988; Johnson, Onwuegbuzie & Turner, 2007).

This approach emphasises the importance of the context, dynamic processes and the naturalistic environment of the research issue and also allows scope for iteration in the research design (Howe, 1988; Johnson & Onwuegbuzie, 2004). In the context of the exploratory nature of the current research, it is important to use an inductive paradigm to ensure the flexibility of the investigation and allow changes of direction in response to anticipated and unanticipated findings throughout the study components (Howe, 1988:12). Moreover, the mixed model permits the researcher to be inclusive, pluralistic and complementary in research design; it allows for blending of the two approaches as appropriate to best address the research questions, the complexities and dynamics of cyclist safety. The mix of approaches was deemed appropriate for the doctoral research described here given the interdisciplinary nature of the broad cyclist safety research questions proposed, drawing from social research, psychology, epidemiology, health research and engineering. To understand literature published in these diverse fields it was necessary to synthesise findings regardless of its epistemological context (Black, 1994).

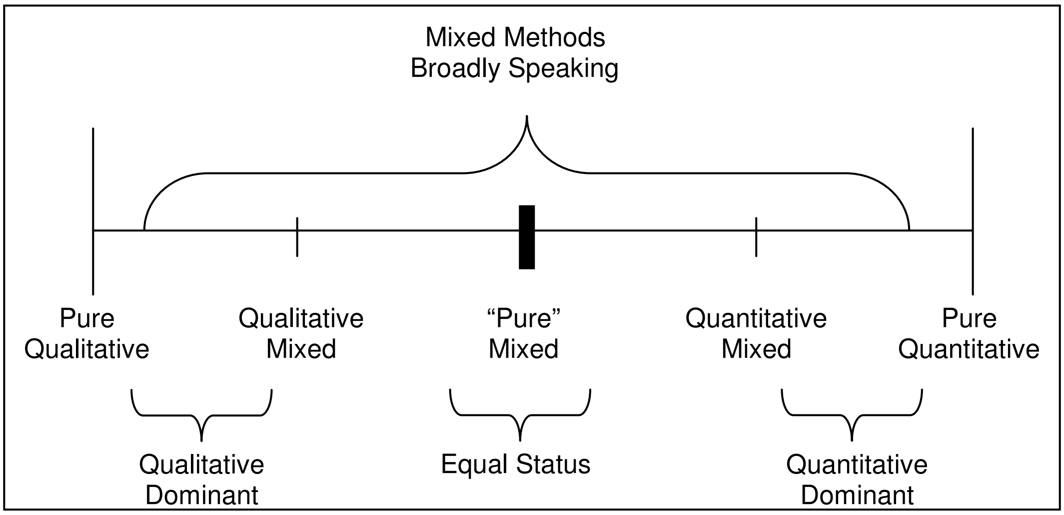

Figure 3-3 The three major research paradigms including subtypes of mixed methods research
Adapted from Johnson et al., 2007: 124

Bryman conducted a comparative study of 232 social science articles to determine how researchers combined qualitative and quantitative methods and how the rationale for using the approaches matched with what the researchers actually used in practice. In the study, Bryman identified a mismatch between the stated rationale and the practice used and identified a greater need for researchers to examine both the rationale for combining qualitative and quantitative research and the way the approaches are combined in practice (Bryman, 2006).

Using Bryman's rationale for a mixed model approach, eight areas were considered applicable to this research program (Bryman, 2006). The components of this rationale are listed below with a brief notation of how each was applied in this research:

1. triangulation or greater validity: findings from each research stage were used to corroborate findings from other stages
2. completeness: a more comprehensive account of cyclist safety was generated by synthesising findings from multi-methods
3. different research questions: four key research questions were studied
4. explanation: each stage provided results but also additional questions, different approaches were needed to help answer the unexpected questions
5. unexpected results: as this was exploratory research, it was anticipated that new and unanticipated results may be generated and hence, another method to enhance the results may be required
6. instrument development: the findings of early stages directly informed the development of later methods
7. context: the combination of findings provided contextual understanding
8. utility: improves the usefulness of the findings

The research adopted the broad mixed model approach as described, combining qualitative and quantitative methods and analytical techniques in three independent but complementary research stages. The three-stage study design is outlined in the next section.

3.3.2 Study design

The review presented in Chapter 2 identified numerous contributing factors in cyclist-driver crashes. However, as discussed, there are limitations in the types of data collected and gaps were identified in knowledge regarding cyclist crash risk factors. In this doctoral research, in-depth studies were undertaken to determine additional risk factors that cannot readily be established from official crash reports.

3.3.2.1 Research stages

The research was conducted in three stages and combined qualitative and quantitative methods and analytical techniques. The staged approach to the research was important in order to allow time to analyse each component and identify the strengths, limitations and major findings before defining the next stage to enhance the previous findings and provide a deeper understanding of the issues related to cyclist safety.

Stage 1: Observational studies

The first stage of the doctoral research was an observational study of cyclists and drivers at selected intersections across metropolitan Melbourne. Findings from the review of studies of cycle crashes provided a starting point for the observational studies. While the crash data provided information on where the cyclist-driver crashes were occurring, there was little information on how these crashes had occurred in terms of cyclist-driver interactions and what other contributing factors may be important to address to improve cyclist safety. To better understand what was occurring at intersections without the potential biases of self-reported behaviour, it was determined that observational studies would provide the most detailed data and be the method that would be most successful in providing new insights into cyclist-driver interactions.

This stage of the research addressed the following research questions:

- *What are the behaviours and characteristics of road users that place cyclists at risk?*
- *What is the role of cycling infrastructure/facilities in cyclist-driver interaction and behaviour?*

Site selection: Sites for observation were selected using the following selection criteria: intersections, in 60km/h speed zones, during the day and in clear weather conditions. To ensure a sufficient volume of both cyclists and drivers, commuter cyclist routes and times were selected. The rationale for focussing on commuter cyclists was presented in Section 3.3.2.2 below.

Data collection: A covertly placed, fixed positioned video camera was used to record the behaviour of all road users who moved through the observation sites. More details about the data collection methods are included in Chapter 4. Video recordings were conducted at each site during morning and evening commuting times.

Data analysis: Two overt non-compliant behaviours were identified and analysed. First, cyclist red light infringement was considered, including the proportion and characteristics of cyclists who infringed, see Chapter 5 (Publication 1). Second, the second analysis focused on cyclist and driver behaviour at different cycling facilities at intersections. Of interest was whether road users' compliance was influenced by the type of cycling facility provided at intersections, see Chapter 6 (Publication 2).

Stage 2: Naturalistic cycling study

The findings of the observational study provided new insights into cyclist and driver behaviour and interactions at intersections. Despite the high number of reported crashes at intersections, no collision or near-collision events were recorded. It was important, therefore, to extend the research in the next research stage, to address the research question:

- *What contributing factors can be identified in cyclist-driver collision and near collision events?*

One of the limitations of the observational study was that the findings were limited to the selected sites, no information was collected for other intersection types or locations and no footage was recorded at midblock locations. Therefore it was important to extend the locations and traffic situations where cyclist-driver interactions were observed.

Development of technique: While point of view cameras have been used in previous research studies including cycling experiences, no other cyclist point of view or naturalistic studies were identified that had deconstructed cyclist-driver collision or near-collision events. As this method had not been used before to investigate the cyclist-driver crash-related events, it was necessary to develop the methodology and data analysis technique. The approach taken was to adapt a naturalistic driving study method, the 100-car study (Neale, Klauer, Knipling, Dingus, Holbrook et al., 2002), to cyclists. The development of the method for the naturalistic cycling study is described in detail in Chapter 7 (Publication 3).

A small compact video camera was attached to the helmet of selected commuter cyclists to record their trips to and from work. Throughout the riders' entire trip, the camera recorded their point of view across all road types, different intersections and on roads with and without cycling facilities. This whole of trip recording offered a much richer data source of cyclists' experiences than the fixed camera recordings of Stage 1.

Participants: A total of 13 commuter cyclist participants each recorded 12 hours of their trips to and from work.

Data collection and analysis: The analysis of these recordings focused on the collision and near-collision events that were recorded and identified the pre-event, event and post-event factors. Over 30 variables were coded and included cyclist and driver behaviours, roads and roadsides as well as cyclist situation awareness and head checks. New insights were gained into the contributing factors in cyclist-driver collision and near-collision events (see Chapter 8, Publication 4).

Stage 3: Online survey

The observational study and the naturalistic cycling study both offered new insights into cyclist and driver behaviour and how the two groups interact. However, questions arose regarding possible motivations for the observed behaviours. For example from Stage 1, what motivated cyclists to infringe at red lights, especially when turning left? Or from Stage 2, how long do drivers indicate before they change lanes or turn left? It was therefore considered important to gain more in-depth information from cyclists and drivers about their knowledge, attitudes and perceptions to understand the potential reason for behaviours that had been observed in the first two research stages.

An online survey was therefore conducted to address these issues. The survey provided the opportunity to ask a range of questions about the behaviours that had been observed in Stage 1 and Stage 2 of the research. The choice to deliver the survey online was to broaden the catchment of the survey; respondents from across Australia would be able to access the survey. Further, in delivering the survey online, rather than in paper form, respondents entered their own responses, this reduced the financial and time costs associated with data entry.

The research questions addressed in this stage were:

- *What are the behaviours and characteristics of road users that place cyclists at risk?*
- *What is the role of cycling infrastructure/facilities in cyclist-driver interaction and behaviour?*
- *How does driver knowledge and attitude influence their behaviour in relation to cyclist safety?*

Development of survey: A range of questions were included that addressed: knowledge of road rules related to cycling facilities, attitudes towards sharing the road with cyclists and behaviour when overtaking cyclists. The survey was delivered online and both cyclists and drivers were invited to participate.

Data analysis: The responses were analysed from drivers and drivers who were also cyclists. The analysis focused on three specific behaviours: overtaking clearance distance, head check before turning left and indicator time prior to turning. In addition, knowledge of road rules related to bike lanes and bike boxes and attitudes about cyclists and sharing the road with cyclists were analysed (see Chapter 9, Paper 5).

3.3.2.2 Participants

The road users focused on in this doctoral research were drivers and adult cyclists who ride on the road.

Drivers were participants in all three stages of the research; however their participation in Stage 1 and Stage 2 was without their knowledge or consent. Drivers were observed with video cameras in both stages to investigate how they interacted with cyclists and it was important that drivers were not aware they were being observed in order to minimise any potential behavioural biases.

In Stage 3, drivers were recruited to participate in the online survey and participation in this stage was with their knowledge and consent. In Stage 3, participants were drivers who both cycled and did not cycle – or who may have cycled when they were a child but did not cycle as an adult.

The adult cyclists were also participants in all three stages of the research and, similar to the drivers, cyclists' participation in Stage 1 was without their knowledge or consent. Again, this was important to minimise behavioural biases that may have occurred if the cyclists had been aware they were being observed. In Stage 2, the cyclists were regular commuter cyclists who regularly rode their commuter trip to and from work and were able to record 12 hours of their trips over a period of four weeks. In Stage 3, respondents who answered that they regularly rode their bike were classified as cyclists. It was likely that these respondents were also drivers.

Throughout the doctoral research, the terms bicycle, cyclist and rider were used as described in the Victorian road rules (Victorian Government Gazette, 1999). Under the Victorian road rules, a bicycle is legally considered a vehicle (RR15 (b)) and a person on a bicycle is considered a rider (RR17 (1)). Throughout the thesis, people riding bicycles are referred to as cyclists or riders. This is distinct from people riding motorcyclists who are referred to as motorcyclists.

In Stage 1 and Stage 2, the main participant inclusion criteria were that i) cyclists travelled primarily on the roads, and ii) cyclists travelled at times when there would also be vehicular traffic on the roads. To ensure an adequate number of cyclists and drivers were observed, particularly in the first observational phase of the study, it was necessary to focus on cyclists who travelled at predictable times and along predictable routes to ensure the robustness of statistical analyses. Commuter cyclists were chosen as the cyclist group that would be observed. This selection was made based on a number of factors:

- both males and females are likely to commute. Although it was expected that there may be an overrepresentation of males on the road as some women have reported to prefer riding on off-road bike paths when available (Garrard et al., 2008)
- commuter cyclists are diverse in terms of appearance including: bike type and clothing
- commuter cyclists are most likely to interact with drivers, as they are the group travelling during peak vehicular travel times

Other cyclist groups were initially considered for inclusion in Stage 1 and Stage 2, however they were excluded as they did not meet the key selection criteria. The other cyclist types considered were bicycle couriers, recreational cyclists, utilitarian riders, training riders and children.

Bicycle couriers are adult riders and cycle sufficient distances to be included in the study however they were excluded for numerous reasons. Typically young males, bicycle couriers are a relatively homogeneous group (Dennerlein & Meeker, 2002). Their travel patterns are determined by the destination of their deliveries and routes are difficult to predict, therefore difficult to observe in sufficient quantities. Further, the greatest concentration of bicycle couriers is in the Melbourne CBD and the city-specific infrastructure of one-way streets, laneways and pedestrian malls would limit the generalisability of the findings to non-city locations. These factors may also affect their frequency and type of interactions with drivers and other road users.

Recreational riders were excluded primarily as their routes are more likely to be off-road and in non-metropolitan areas with low traffic density. It was considered that it would be difficult to locate sufficient on-road volumes of recreational cyclists. Utilitarian riders were also excluded as riding for local trips is not common practice in Australia and it would be difficult to observe sufficient volumes of cyclists. Further, as with bicycle couriers, route unpredictability was a concern with utilitarian cyclists.

Training cyclists including professional, semi-professional and amateur cyclists were also excluded. This group was considered too homogenous and consequently there would be limited applicability of the findings to broader cyclist groups. Training cyclists in Melbourne are predominately male, ride similar, top-end (expensive) road bikes, wear full cycling attire consisting of padded lycra pants and cycling jersey, often in professional or amateur team colours and tend to ride specific routes (O'Connor & Brown, 2007). Moreover, the behaviours of these cyclists is potentially quite different to that of commuter cyclists. In Melbourne, the volume of on-road training cyclist is increasing and regular rides attract bunches of cyclists from 6 to 100+ riders (Johnson et al., 2009). However, pilot observations found that there were few vehicles on the road during the peak training cyclist riding times thus offering little opportunity to study cyclist-driver interactions. Although this type of cyclist was excluded in this research based on the above factors, understanding the factors surrounding this group’s safety is an important area for future research, particularly in cities and communities with an increasing number of on-road training groups to ensure the safest environment for cyclists, drivers and pedestrians.

Children were excluded as a cyclist group from this study for numerous reasons. Children at different ages have varying abilities to safely negotiate traffic and manoeuvre themselves in the road environment. It was beyond the scope of this research to fully explore the complexities of childhood developmental stages as they relate to cycling and cyclist safety. Furthermore, in Victoria, children up to 12 years of age are permitted to cycle on the footpath, as such child riders were less likely to interact with drivers. Cyclist crashes on the footpath have different characteristics to on-road crashes and include crashes related to footpath surface, vehicles reversing from driveways and entering the roadway from the footpath. Finally, observations were a key data collection method in Stage 1 of this doctoral research and cyclists were observed without their knowledge or consent. The researchers had ethical concerns regarding targeting children for covert filming without parental knowledge or consent (Slack & Rowley, 2000).

3.3.3 Research matrix

Each stage of the research was designed to address some or all of the research questions and the components of the Safe System Framework. Figure 3-4 below shows the matrix of the components of the SSF and the association with each stage of the research.

Each stage of the doctoral research informed subsequent stages, as indicated by the arrows in the first column in Figure 3-4. Across the three stages, three components of the SSF were addressed, being safer road users, providing safer roads and the secondary component: understanding crashes and crash risks.

Research stage	Safe System Framework component			
	Safer road users (cyclists and drivers)		*Safer roads and road sides*	*Understanding crashes and risks*
	Behaviour	Attitudes and perceptions		
1. Observational study	✓		✓	
2. Naturalistic study	✓		✓	✓
3. Online survey	✓	✓	✓	✓
Safer travel				

Figure 3-4 Matrix of the Safe System Framework and research stages

It was anticipated that the research findings would inform educational and awareness programs that address both cyclists and drivers and would include the cycling-related components of the road environment. In particular, the findings will be used to inform programs developed by Amy Gillett Foundation to increase awareness of cyclist safety issues and improve cyclist safety. Further, the research findings were presented to government departments, including the state road authority, VicRoads, and may potentially be used to inform government policy.

3.3.4 Ethics

The research protocol for each stage was reviewed and approved by the Monash University Human Research Ethics Committee. A copy of each certificate of approval is included in the appendices.

The primary ethical concern was related to the extensive use of video recordings in Stages 1 and Stage 2 and the need to protect the confidentiality of individuals in the images recorded, in particular cyclists' faces and vehicle licence plate details (Rosenstein, 2002). In the piloting for Stage 1, the camera was positioned ahead of the cyclists and some cyclists' faces were recorded and would have been identifiable by the cyclists or someone who knew the cyclist. However this footage was only used to determine appropriate site selection and is stored in a password protected electronic file in accordance with university policy. Ultimately, the camera for Stage 1 was positioned behind the road users so that no cyclists' face was recorded. Vehicle licence plates were recorded and it is proposed that these images will be blurred for all public presentations.

Similarly in Stage 2, the participants' face was not visible as the camera was positioned on their head, and any identifying features of other road users will be blurred in excerpts of footage that are presented publicly. There were no unusual ethical concerns associated with the online survey conducted in Stage 3.

Summary

In summary, during the mid-twentieth century, there was a definite shift in the concepts of injury prevention science from accident to injury and the recognition that broader factors contributed to injurious events than the injured person's actions. A reconceptualising of accident by Gordon (1949) was achieved and refined by the application of the epidemiological structure of disease causation to understanding injurious events, was further refined by Gibson (1961) and Haddon (1963). A similar systems based approach was also developed by Rasmussen (1982) and Reason (1990) in the risk management field; however, it was the 1990s before this approach was adopted in road safety, beginning with the Dutch Sustainable Safety approach and the Swedish Vision Zero.

In Australia, the Safe System Framework was adopted in the early 2000s and the SSF version of the Victorian road safety strategy was used as the theoretical framework for this doctoral research. The focus was specifically on three key components of the SSF, safer road users, safer roads and roadsides and understanding crashes and crash risk.

A mixed method approach (Johnson & Onwuegbuzie, 2004) was used in this doctoral research. The approach was a pragmatic philosophical perspective and used qualitative and quantitative methods as appropriate. The doctoral research was undertaken in three stages: 1) an observational study; 2) a naturalistic cycling study, and; 3) an online survey. Each study built on the findings of the previous study to deepen the understanding of issues that affect cyclist safety. Commuter cyclists were the primary focus for Stage 1 and Stage 2.

Collectively, the three research stages addressed three components of the SSF and it is anticipated that the findings will be used to inform cyclist safety programs and government policy.

The next section of the thesis describes the three stages of research with the publications from each stage inserted in the format of the journal in which it was published (see Chapters 4-9). The thesis concludes with a synthesis of findings presented in Chapter 10.

Chapter 4

Stage 1 research design

In Stage 1 of this doctoral research, an observational method was used to study cyclist and driver behaviours, interactions and to examine contributory factors to collision or near-collision events. A pilot study was conducted to develop and refine the approach before undertaking the main observational study. The preparatory tasks and pilot study are outlined in this chapter.

In the Stage 1 observational study, the following two doctoral research questions were addressed:

- *What are the behaviours and characteristics of road users that place cyclists at risk?*
- *What is the role of cycling infrastructure/facilities in cyclist-driver interaction and behaviour?*

4.1 Method

Observational methods are used to 'gather first hand information about social processes in the "naturally occurring" context' (Silverman, 2001: 14), and generate data on how people actually behave, rather than their self-reported behaviours (Conche & Tight, 2006). The observational technique selected as the most appropriate for this study has been referred to as the *complete observer* (Gold, 1958), wherein the researcher has no interaction with the participants. Road users were not approached and no interventions were introduced that may have influenced behaviour. This noninterventionist approach (Adler & Adler, 1998) enabled data to be generated using a large sample of road users engaging in everyday travel activities without any intervention that may affect behaviour.

A video camera was used to record the observations and created a permanent record. This allowed for post-observation analysis to identify and scrutinise patterns of behaviour amongst specific road users (Rosenstein, 2002; Paterson, Bottorff & Hewat, 2003; Ferrándiz & Baer, 2008; McNaughton, 2009). There are numerous benefits of using a video camera over ‘manual’ observations, particularly as the participants were interacting in a complex and dynamic environment. At peak times, human observers conducting manual observations can be overburdened and as a result, details may be omitted or incorrectly recorded (Arnberger et al., 2005). Unlike human observers, the camera is not susceptible to fatigue or recording errors and the footage can be reviewed repeatedly (van der Horst, 1990; Rosenstein, 2002). Further, the video recorded all behaviour, which meant details that may not have been considered important a priori were still captured and could be analysed post hoc.

In addition, the video recording method eliminated three potential biases. Firstly, reporting bias was eliminated through use of covert video monitoring. It was anticipated that the behaviours of interest may be illegal and/or unsafe and participants may have been reluctant to admit to such behaviours if asked directly.

The second potential bias was recall bias. It is possible that cyclists and drivers may not recall or are not fully cognisant of the detailed behaviours of their everyday travel and, more importantly, behaviours that immediately preceded an event. It was considered unlikely that reliance on road users’ memory alone would provide accurate and/or new insights.

The third potential bias was behavioural bias and the potential for behaviour change when individuals are aware that they are being observed (Slack & Rowley, 2000; Dholakia & Sinha, 2005). Covert positioning of the camera was used to minimise this bias as a roadside camera position was considered too conspicuous. The process was undertaken to identify the ideal camera position is discussed in this chapter.

An additional potential bias of any data collection is inter-rater reliability. As the observations were video recorded, the footage was analysed and coded by the researcher. Inter-rater reliability testing was then conducted. This involved recoding a proportion (approximately 10 per cent) of the raw data (video footage) by an independent researcher to evaluate the reliability/objectivity of the researcher's coding. The Kappa statistic was used and the statistic was interpreted using Landis and Koch's measurement of agreement. The Kappa score is included in the publications as appropriate.

4.2 Pilot observational study

The pilot observational study was conducted over four weeks during January and February 2008. The objectives of the pilot study were to determine the following for the main observational study:

- trial the method of data collection and evaluate its feasibility
- determine the required length of observation time and times of day
- select intersection types and locations
- conduct a preliminary evaluation of the footage

Each of these four objectives is addressed below.

4.2.1 Data collection method, trial and feasibility

A Sony DCR-SR62 video camera was used for the data collection. The standard battery was upgraded which increased recording time capacity to 3 hours and 40 minutes. The frame rate was set at the camera's highest resolution of 30 frames per second, capturing a clear image of all road users who travelled through the site, regardless of speed (Arnberger et al., 2005). During the pilot study, the camera was positioned in a parked private vehicle (study vehicle) and the researcher stayed in the vehicle during all observations. No attempt was made to hide or disguise the camera.

In the pilot study, a total of eight observational sessions were conducted. During six of the sessions, the camera was placed on the dashboard above the steering wheel and filmed passing traffic through the front windscreen. In this position, the camera recorded road users as they passed the study vehicle including their movement through the intersection and the status of the traffic lights. This allowed for accurate observations of road users' behaviour during the traffic light phasing.

Post observation analysis of the video recordings showed that the road users did not look towards the camera, therefore, it was reasonable to assume that they were unaware they were being filmed. However, the method was reliant on a vacant parking bay in the vicinity of the selected intersection, which was not always available. In addition, the view of the intersection was completely obscured when vehicles stopped illegally in front of the first parking bay. Frequently couriers and delivery vans stopped to make deliveries while private vehicles and taxis used the space to stop and pick up or drop off passengers.

To address these limitations, an alternative camera position was tested. For two observation sessions, the car was parked on the opposite side of the intersection, the camera was placed on the rear parcel shelf and approaching traffic was filmed through the rear windscreen. The parcel shelf position provided greater opportunity to observe the interaction between cyclists and drivers compared with the dashboard as the perspective was rarely blocked by traffic, and a forward facing view of road users was available. However, from the cyclists' head movements towards the camera it appeared that some cyclists noticed the camera. While no one approached the researcher, this camera position may have potentially introduced a behavioural bias. A further limitation of the parcel shelf camera position was that this did not allow a view of the traffic lights.

To address the limitations of the in-vehicle camera positions, a more suitable exterior location was explored. The alternative chosen for further piloting was a custom-made 'camera box' that could be attached to a roadside signpost, developed by Archer (Archer, 2008). Two short (30 minute) observations were conducted and the camera box provided a clear, unimpeded view of the intersection. As the camera was attached to a signpost, the observation was not reliant on the availability of a specific parking bay.

The camera box was wooden, painted grey, approximately the size of a small shoe box and was designed to be attached to a standard signpost (19.5cm circumference) that is typically used to display parking time details. The box was positioned immediately under the sign, approximately 2m from the ground. The camera was positioned inside with the lens positioned to enable unobstructed filming through a hole cut into the front of the box, see Figure 4-1. In the main observational study, the camera box was attached to the same signpost at each site and was removed at the end of each observation. The camera was positioned at approximately the same angle for all observations at each site.

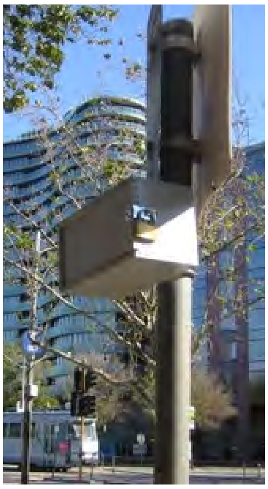

Figure 4-1 Observational study camera box

One modification was made to the camera box after the commencement of the main study. During one of the early observation sessions, a cyclist locked his bike to the signpost and knocked the camera out of position. The camera then filmed the inside of the box for the remainder of the observation session resulting in an incomplete observation. To address this, the camera was secured to the floor of the box using Velcro tape. Subsequent knocks to the signpost did not affect the camera position.

After the successful camera box pilot, the next step was to determine the length of time for each observation session and the time of day that each session would be conducted.

4.2.2 Site selection

Intersections were identified as the focus of the Stage 1 observations based on the reported over-representation of bicycle-vehicle collisions at intersections, particularly in low speed zones and in urban areas (Australian Transport Safety

Bureau, 2006; Watson & Cameron, 2006). Intersections are considered the most dangerous part of the road network, because they present road users with several potential points of conflict with other road users, often at high speeds (Carter, Hunter, Zegeer, Stewart & Huang, 2007).

In Melbourne in 2007, the most frequently used on-road cycling route during peak travel times was a major arterial road from the Melbourne central business district (CBD) to the south-eastern suburbs (City of Melbourne, 2007). The road, renamed at different sections, begins in the CBD as St Kilda Road, becomes Brighton Road and then the Nepean Highway. The section of road considered for the pilot study began in the Melbourne CBD on the corner of Swanston Street and Flinders Street and continued along St Kilda Road for 6.2 km and is represented by the blue line in Figure 4-2.

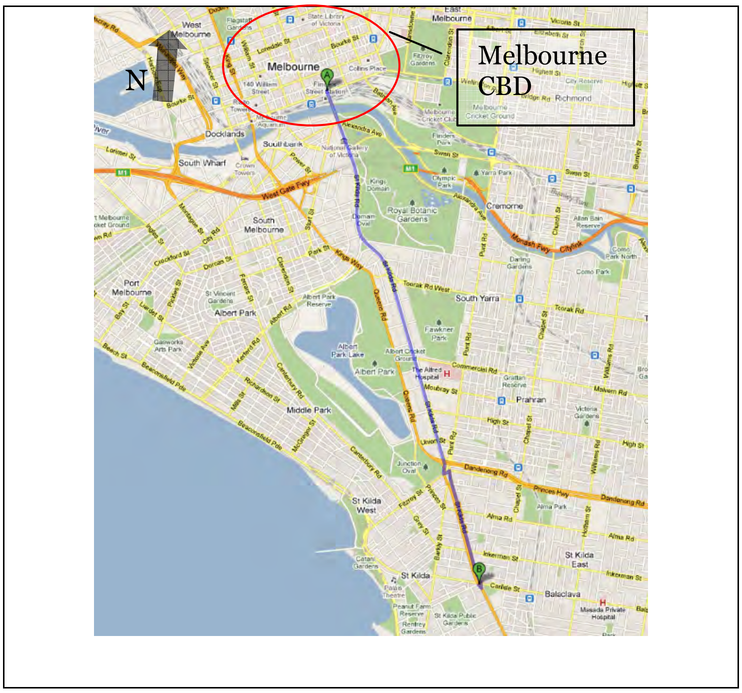

Figure 4-2 Pilot study - route considered for site selection (Google, 2010)

The following assumptions were made in the selection of road for the observations:

- the Swanston Street/Flinders Street intersection is the main on-road access point to the CBD from the south-eastern approach therefore it was reasonable to measure cyclists' trip distance from this intersection

- cyclists would be travelling at least the average commuter trip distance, between 5.1-10km each way on each inbound and outbound trip (Bicycle Victoria, 2009)
- restricting the route to 6km from the CBD would capture a large proportion of commuter cyclists
- if observations were extended further along the route it was likely that the volume of cyclists would diminish as riders turned off into residential streets

Along the 6.2km section of road there was a dedicated bike lane, typically a single white line positioned between the parallel parking bay and the left vehicular lane with an occasional painted bicycle symbol. The bike lane was continuous along the midblock sections of road and discontinued on approach to most of the intersections on the route. At some intersections, the bike lane continued to the intersection and short sections of the bike lane were painted green. All cross-intersections and most pedestrian crossings were signalised and there were a number of T-intersections, both signalised and unsignalised on the route. The speed zone was mainly 60km/h with one designated timed 40km/h school zone (approximately 500m in length). A tram line ran parallel to the right vehicular lane along the entire length of selected road section.

In total, eight sites along the designated route were selected as observational sites in the pilot study. Sites were selected to include a range of intersection types. It was anticipated that road user behaviour would vary across the different sites. Three types of intersections were observed and are discussed below.

Cross intersection sites

Five signalised cross intersections were observed, three in the morning and two in the afternoon. Four of the sites had two vehicular lanes for through traffic and one left turn lane. There was a bike box in front of the left turn lane as shown in Figure 4-3.

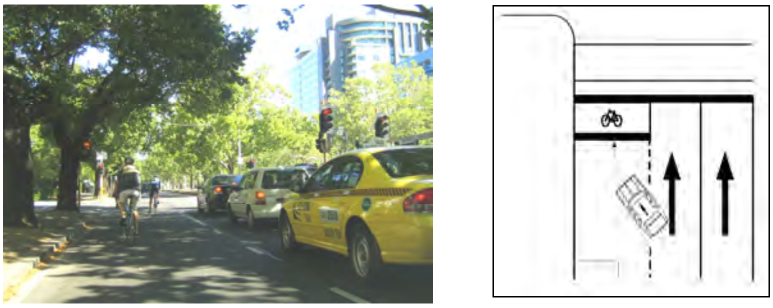

Figure 4-3 Pilot site, cross intersection

The midblock bike lane was discontinued on approach to the intersection and there were no line markings connecting the bike lane and the bike box.

One cross intersection was more complex than others with three vehicular lanes for through traffic and a dedicated left turn with a filter light. The filter light comprised a green turn arrow, permitting traffic in that lane to turn left while the through lanes of traffic still faced a red light. The cross roads at this intersection were four vehicular lanes and tramlines. The bike lane markings changed from a solid white line along the midblock section to a dashed white line to mark a space for drivers to cross the bike lane, with solid lines appearing again at the intersection. There was no bike box at the intersection and the bike lane did not continue through the intersection (see Figure 4-4).

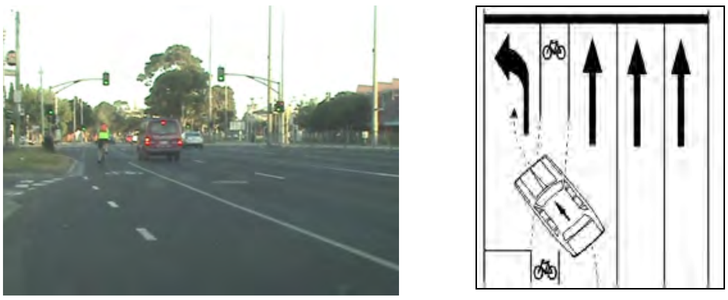

Figure 4-4 Pilot site, cross intersection (complex)

T-intersection sites

Two T-intersections were included as observational sites, one signalised (morning) and one unsignalised (afternoon). At the T-intersection for morning observations, cyclists rode across the ‘top’ of the intersection and continued straight. At this site, the design did not require cyclists to cross the path of vehicular traffic. The morning site had two vehicular lanes for through traffic and the midblock bike lane discontinued on approach to the intersection. There was a bike symbol but no bike box at the intersection (see Figure 4-5).

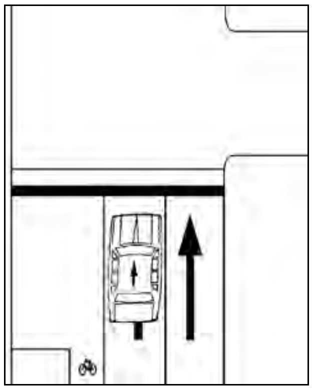

Figure 4-5 Pilot site, signalised T-intersection

The unsignalised T-intersection site had three vehicular lanes. The painted bike lane was a solid white line midblock and a dashed line over the intersection (see Figure 4-6). To enter the T-intersection cross traffic had to cross the dashed bike lane and before exiting the T-intersection road users were required to yield at a give way sign.

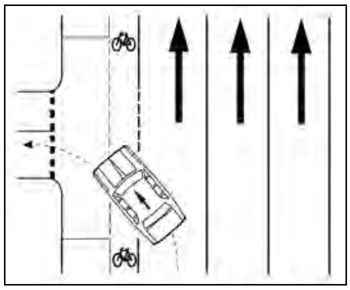

Figure 4-6 Pilot site, unsignalised T-intersection

Pedestrian crossing

One pedestrian crossing was observed in the afternoon. This site had two vehicular lanes for through traffic and a bike lane that discontinued on approach to the pedestrian crossing, see Figure 4-7.


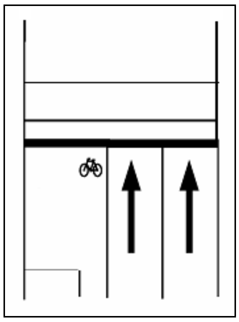

Figure 4-7 Pilot site, pedestrian crossing

Following each pilot observation session, the video footage was downloaded and a back up copy was made of the data. The camera hard drive was reformatted (erased) and the battery recharged, ready for subsequent recordings. The footage was analysed before the sites for the main observational study were selected. The analysis of the footage is discussed next, followed by the details of the main observational study.

4.2.3 Preliminary evaluation of the cyclist and driver behaviours

In total, during the pilot study 16 hours of footage was recorded, 2 hours at each of the 8 sites. Descriptive measures that were extracted and coded from the video recordings for further analysis included: site, day, time, distance from the CBD, position of the camera, type of intersection, cycling facility at the intersection, number of cyclists. Cyclist gender was coded based on physical appearance, given the temperate weather, cyclists wore light clothing and gender was easily identifiable. Cyclists' compliance behaviour at red lights was also extracted and coded; with an infringement defined as continuing across an intersection during the red light phase. The descriptive statistics for each site are presented in Table 4-1.

In total 3,037 cyclists were observed. The majority of riders were male (86.1%) and the proportion of female cyclists varied across the sites from 8 to 17 per cent. Compared with the Australian cycling participation data (males 65.1%), males were overrepresented in the pilot study (Department of Communications Information Technology and the Arts, 2009). This was not surprising, as the pilot study sites were all on-road and females reportedly prefer off-road routes and routes with higher cycling facilities and/or segregation (Garrard et al., 2008).

Table 4-1 Summary data for the pilot observational study

	1	2	3	4	5	6	7	8	
Time	AM	AM	AM	AM	PM	PM	PM	PM	
Day	Thurs	Thurs	Fri	Tues	Thurs	Wed	Thurs	Tues	
Date (2008)	17 Jan	24 Jan	25 Jan	19 Feb	17 Jan	23 Jan	24 Jan	19 Feb	
Distance from CBD (km)	6.0	3.4	2.8	4.3	5.7	2.8	0.9	4.3	
Position of camera	Dash	Dash	Dash	Parcel	Dash	Dash	Dash	Parcel	
Type of intersection	Complex Cross	T (lights)	Cross	Cross	T (no lights)	Cross	Ped'n	Cross	
Cycling facility at intersection	Standard bike box	None	Standard bike box	Standard bike box	None	Standard bike box	None	Standard bike box	
Cyclists									**Total**
Number of cyclists	282	418	322	478	270	376	453	438	3037
Gender (male)	245 (87%)	357 (85%)	280 (87%)	394 (82%)	245 (91%)	311 (83%)	379 (84%)	405 (92%)	2616 (86%)
Cyclist behaviour									
Faced red light (infringed)	146 (1%)	100 (22%)	115 (5%)	228 (1%)	-	45 (9%)	6 (100%)	221 (18%)	861 (8%)

No collision or near-collision events were observed during the pilot study; therefore the focus of the analysis was on observed behaviours. Overall, a relatively small proportion of cyclists who faced the red light infringed (8%). From the descriptive statistics, it appeared that several factors may be predictive of red light infringement including: time of day, gender and intersection type. An in-depth study of cyclist red light infringement was conducted and is presented in Chapter 5 (Publication 1).

Bike boxes were present at five of the pilot observation sites. In general, drivers were observed to be non-compliant at intersections with bike boxes as many stopped within the boxes or encroached into the boxes during the red light phase. This behaviour suggests a failure to comply with or low awareness/understanding of the requirements of this cycling facility. The behaviour of cyclists and drivers in relation to cycling facilities at intersections was investigated in Chapter 6 (Publication 2). Cyclist and driver understanding and behaviour at bike boxes were further explored in the Stage 3 online survey and are included in Chapter 9 (Paper 5).

Based on previous research, it was expected that the video recordings would capture cyclists' head check behaviour and that this would provide important data on cyclists' situation awareness and looking behaviour. Räsänen, Koivisto and Summala's (1999) conducted video observations of yield behaviour at intersections to examine compliance with changes in Finnish vehicle priority legislation. Cyclists' head movements were used as an indication of visual scanning behaviour: more frequent head movements were associated with greater caution (Räsänen, Koivisto & Summala, 1999). However, close inspection of the video recordings from the pilot study showed that cyclist head checks were only clearly visible when the camera was positioned on the parcel shelf (Observations 4 and 8). Thus, the use of the camera box for the main study precluded measurement of cyclists' head check behaviour was not considered a reliable measure and therefore not included in the Stage 1. This limitation was addressed in the methods used in Stage 2, the naturalistic cycling study.

Overall, the pilot study demonstrated the feasibility of observing the behaviour of cyclists and drivers and their interactions at a range of intersections. The pilot study afforded an important opportunity to confirm the data collection methods, identify appropriate measurement and analysis of variables and identify and rectify problems prior to the main study (van Teijlingen & Hundley, 2001).

4.3 Study 1 – Observational study

The main observational study was conducted with some adjustments as a result of the findings of the pilot study. Observations were over three periods: March 2008, October 2008 to end of March 2009 and March 2010, during the Australian months of spring, summer and the first month of autumn (fall). These months also included the entire period of daylight savings in Victoria with daylight hours from approximately 6.30-7am to 8-9pm.

In total, eight sites were selected as observational sites. Observations were conducted at two sites in March 2009 and again in March 2010, resulting in 10 observational sessions. The data collection method and sites selected are described below.

4.3.1 Observation times

Previous studies of cyclist-driver behaviour were reviewed for guidance on suitable observation periods. No standard approach was evident. For example three sessions over 9 hours were recorded to examine drivers' looking behaviour in relation to cyclists (Summala et al., 1996; Räsänen & Summala, 2000) while observation of bicycle helmet compliance, ranged from 1 hour (McGuire & Smith, 2000) to 27 hours over 4 days (Farris, Spaite, Criss, Valenzuela & Meislin, 1997). Importantly, for the proposed study, it was critical to record a sufficient volume of road users to ensure power in the statistical analysis and a sample as representative as possible.

The approach used to determine the length of observation sessions was the Swedish Traffic Conflict Technique developed at the University of Lund in Sweden during the 1970s and 1980s (Archer, 2005). The technique was developed to investigate observational data of near-conflict events, whereby the actions of road users would lead to a collision unless avoidance behaviour was taken. The approach specifies that to obtain a representative sample of road users, it is necessary to record 18 hours per site across several days (van der Horst, 1990; Archer, 2008). In previous applications of this method, observations were conducted at intervals across a 24-hour period, including peak and off-peak periods (Archer, 2005). However, it was expected that for the purpose of the current study, there would be little benefit in recording throughout the day, as few cyclists ride through the sites outside the main commuter times. Therefore, each site was observed for the three hours during either the morning or afternoon peak traffic periods, across six non-consecutive days.

Peak traffic times in a 10 kilometre radius of the Melbourne CBD are from 6.30am to 10am in the morning and from 3pm to 7pm in the afternoon/evening (VicRoads, 2008a). A total of three hours during each of these peak travel periods were observed. In the morning, observations were conducted from 7am to 10am. A 7am start time was selected due to low light conditions prior to 7am. By restricting the morning start time until 7am most of the morning observations over the summer daylight savings months would be in the daylight. In the afternoon, the three-hour observation period was from 4pm to 7pm in order to capture the main volume of commuting cyclists within daylight hours. Preliminary observations showed that there was little cyclist traffic at the designated on-road sites before 4pm.

4.3.2 Data collection method

The camera box was used for all observational sessions. Each observation session was conducted for a period of 3 hours, during the morning (7-10am) or in the afternoon/evening (4-7pm). Six observation sessions were conducted at each site over non-consecutive days, resulting in 18 hours of video footage per site. All observation sessions were conducted during peak travel times and it was assumed that the majority of road users were commuters. No cyclists or drivers were observed making head checks or turning towards the camera during the observation period, indicating they were unaware they were being filmed. Due to security concerns, the researcher stayed in a vehicle in close proximity to the camera throughout the observations.

All recordings were conducted using one camera and sometimes observations were conducted in the morning and afternoon on the same day along the same route. The same person could not be counted twice during a single observation session, however they could be recorded again later on in the same day. Further as the same sites were observed over six non-consecutive days, it is highly likely that the same road user was observed in more than one session. The implications of multiple recordings of individual road users, in particular cyclists, are discussed in Chapter 5 (Publication 1).

As the majority of all cyclist deaths (Australian Transport Safety Bureau, 2006) and serious injuries (Watson & Cameron, 2006) occur during dry, clear conditions, it was considered a priority to maximise the observation on days with such conditions. Observations were not conducted on days when the forecast temperature exceeded 35°C or on days with rain during the morning observation.

4.3.3 Selected sites – cycling facilities

As found in the pilot study, the greatest variance in road user behaviour in the main study was observed at the cross intersections (see Table 4-1). Three different cycling facilities were selected for observation as it was anticipated that road user behaviour would vary across the different site types. The cycling facilities chosen were the most common at Melbourne intersections and could be matched in terms of road geometry for morning and afternoon observations.

The first site type was referred to as the 'standard' site as this was the most common cycling facility. The sites had two vehicular lanes for through traffic and a left turn lane with a bike box in front of the left turn lane. There was no left turn filter light at the standard sites observed (see Figure 4-8). Four standard sites were selected for observations.

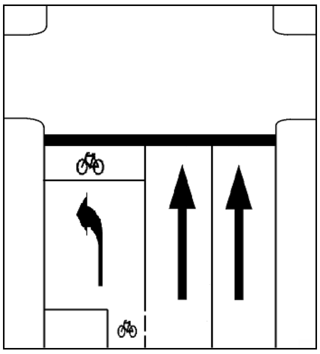

Figure 4-8 Standard intersection

The second site type was referred to as the 'centre' site as the bike box was positioned in front of the centre vehicle lane, see Figure 4-9. This site type had two vehicular lanes for through traffic and a dedicated left turn lane with a filter light. Two sites of this type were selected for observations.

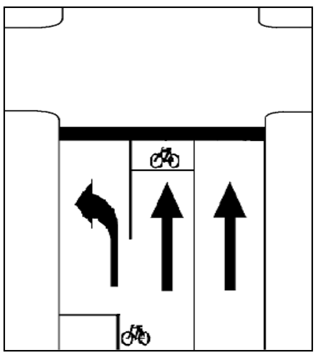

Figure 4-9 Centre intersection

The third site type selected for observation was the ‘continuous’ site and two sites were selected. At these sites, there were two vehicular lanes for through traffic and the midblock bike lane continued to the intersection, although it did not continue through the intersection. The vehicle lanes continued in parallel with the bike lane and the space for the cyclists did not encroach on the vehicle space. There were no cycle line markings through the intersections, see Figure 4-10.

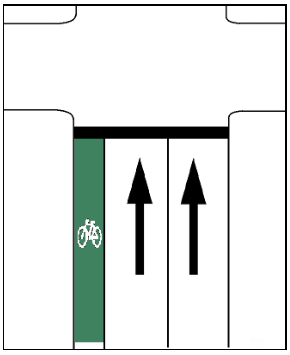

Figure 4-10 Continuous intersection

4.3.4 Selected sites – locations

In an effort to increase the representativeness of the sample, sites were selected from across metropolitan Melbourne. Potential observation sites were considered along the most popular on-road cyclist commuter routes into the Melbourne CBD. The three main routes identified for the study provided approaches to the CBD from the south-east, north and north-west Several other routes into the CBD were excluded for various site-specific reasons such as cyclist off-road travel at the intersection and non-representative vehicle mix including high volume of over-dimensional trucks.

The locations for the sites for the main observational study are mapped on Figure 4-11 below. The red oval in the centre of the map indicates the Melbourne CBD and the green lines indicate the selected cyclist commuter routes. The observation sites are numbered in orange. Table 4-2 provides additional information about each site (note corresponding numbers of sites on Figure 4-11) including approach, cycling facility present and direction. All sites had a tramline parallel to the right vehicular lane.

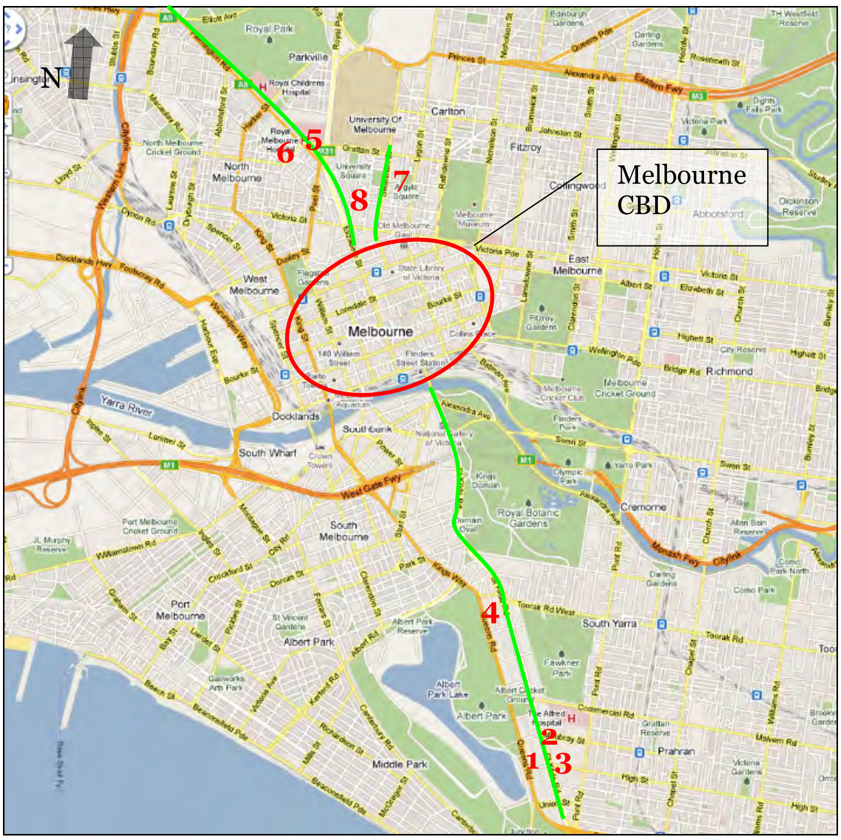

Figure 4-11 Location of observational sites
(Google, 2010)

Table 4-2 Stage 1 observation sites

Approach	Cycling facility	Direction	Site Number	Location
South eastern	Standard	Inbound*	1	St Kilda Rd and Lorne St
		Outbound*	2	St Kilda Rd and Moubray St
	Centre	Inbound	3	St Kilda Rd and Kings Way
		Outbound	4	St Kilda Rd and High St
North western	Standard	Inbound	5	Flemington Rd and Grattan St
		Outbound	6	Flemington Rd and Wreckyn St
Northern	Continuous	Inbound	7	Swanston St and Queensberry St
		Outbound	8	Swanston St and Queensberry St

* These sites were observed twice, in March 2009 and in March 2010

Summary

An observational method was developed and used for Stage 1 to study the behaviour of cyclists and drivers. This non-interventionist approach was chosen as it eliminated three potential biases: reporting bias, recall bias and behavioural bias. Measurement bias was also addressed using tests of inter-rater reliability. A pilot study was conducted and was successful in refining the data collection method and determining key components and variables for the main observational study.

A covertly positioned video camera was used to record cyclists and drivers behaviour at intersections. Three hours of observations were recorded per session, with sessions conducted over six non-consecutive days. All observations were conducted during the peak travel times, in the morning from 7am to 10am and in the afternoon from 4pm to 7pm.

Preliminary analyses of the pilot study footage informed the final site selection. Eight cross intersections were selected for the observation sites along three on-road cycling commuter routes into the Melbourne CBD.

Following the successful pilot study, the full observational study was conducted. The details of this study and two journal articles based on these data are presented in the following two chapters.

Chapter 5 Publication 1

Cyclist red light infringement

The aim of this doctoral research was to identify ways to improve safety for on-road cyclists. One of the key approaches to identifying risk factors was to understand crash and crash risk by investigating the moments just before a collision or near-collision occurred and identifying the main contributing factors. However, despite over 300 hours of observational footage being recorded in the Stage 1 observational study, no collision or near-collision events were recorded. While the lack of crash events is a positive outcome for cyclists and the other road users observed, the footage did not provide an opportunity to investigate the mechanisms of a crash event. In lieu of any crash events, cyclist behaviour from the footage was analysed and both publications addressed the first research question:

- *What are the behaviours and characteristics of road users that place cyclists at risk?*

The first publication, presented in this chapter, focused on the cyclists' behaviour at red lights including infringement and the second publication, presented in Chapter 6, explored cyclist and driver behaviour at different cycling facilities at intersections.

Cyclist red light infringement is arguably the most obvious cyclist behaviour that is illegal and potentially unsafe. There has been relatively little attention given to the rate and characteristics of cyclists who infringed at red lights. One observational study in Melbourne reported that 9 per cent of cyclists infringed at red lights at urban intersections (Daff & Barton, 2005). While cyclists' self-reported rate of red light infringement is considerably higher. A survey based study of commuter cyclists in Brazil reported that 38.4% of cyclists infringed at red lights (Bacchieri, Barros, dos Santos & Gigante, 2010). No further details were provided about the characteristics of non-compliant cyclists.

In Victoria, cyclist red light infringement has attracted extensive media attention with calls for greater enforcement and tougher penalties for non-compliant cyclists (Ferguson, 2006; Silkstone & Burrow, 2006; ABC News, 2007; Harrison, 2007). The current Victorian government road safety policy *arrive alive 2008-2017* (VicRoads, 2008b) includes a recommendation for a review of penalties for cyclists' behaviour to ensure they equate to driver penalties. However, despite the attention given to red light infringement, the extent of cyclist infringement in Melbourne was not known. Although Daff and Barton reported 9 per cent in 2005, data collection was not ongoing and it was not known how this proportion may have been affected by the increase in the number of people cycling.

The extensive video footage generated in Stage 1 of this doctoral research provided a perfect opportunity to analyse the behaviour of thousands of cyclists to determine the rate of infringement as well as details of the characteristics of cyclists both compliant and non-compliant. Such information might then be used to inform more targeted countermeasures and inform road safety policy.

Red light infringement is the most overt illegal behaviour for all road users and is reported to be a significant road safety problem: between 10-30 per cent of vehicle crashes at signalised intersections involve traffic signal violation (Green, 2003). Driver infringement, defined as a vehicle crossing the intersection stop line after the onset of the red traffic light (Green, 2003), has been widely researched. Non-compliant drivers tend to be a higher risk-taking group than compliant drivers, have poorer driving records, are less likely to wear a seat belt and more likely to be younger drivers (Retting & Williams, 1996; Retting, Ulmer & Williams, 1999; Porter & England, 2000; Porter & Berry, 2001; Romano, Tippetts & Voas, 2005; Herbert Martinez & Porter, 2006). Additionally, Porter and Berry (2001) reported non-compliant drivers were more likely to be travelling alone, in a hurry and increase their speed to beat red lights compared with compliant drivers. Driving with passengers, especially children reduced drivers' likelihood of red light infringement (Porter & England, 2000; Porter & Berry, 2001). A summary of selected research that investigated driver red light infringement, including the definitions for infringement, are included in Table 5-1.

In the pilot study, discussed in Chapter 4, the proportion of non-compliant cyclists was identified (8%). The analysis of red light infringement presented in this chapter extended the findings of the pilot study by expanding the sample size and including multiple observation sites. This was important in order to reduce potential site-related bias and increase the statistical power of the analysis of key factors that influence red light infringement.

Publication 1

In the publication, a total of 90 hours of footage was analysed. The analysis included footage from 10 sites, 5 morning sites and the 5 matched afternoon sites, and 3 observations for each site (i.e. 9 hours). As described in Chapter 4, the 10 observations included all 8 different sites with sites 1 and 2 observed twice. The 3 different cycling facilities were included: standard, centre and continuous.

In total, 4,225 cyclists were observed and in total 6.9 per cent of cyclists infringed at the red light. Key factors that influenced red light infringement were direction of travel (turning left), cyclist gender (male) and cyclists were more likely to infringe at the intersection with the centre bike box than the other two facility types. The presence of other road users had a deterrent affect on red light infringement; presence refers to drivers and other cyclists being in the same lane travelling in the same direction as well as the volume of cross traffic. It was not surprising that as the volume of cross traffic increased the likelihood a cyclist would infringe against a red light decreased.

Table 5-1 Summary of selection research that investigated driver red light infringement

Author(s) & Year	Location	Methods/participants	Infringement definition, key outcomes and recommendations (rec's)
Retting & Williams, 1996	United States of America	Manual observations and red light cameras n=1,373 drivers	Definition: vehicles that entered intersection ≥0.5 second after onset of a red traffic signal. Turning vehicles were excluded due to right on red law. Left turn lanes were not observed 33.6% of drivers non-compliant, av. 2 infringements/hr May underestimate infringement rate, only one vehicle was recorded per light cycle Violators had more infringements, poorer driving records, younger, less likely to use seat belts, no gender differences Rec's: increased enforcement (red light cameras), increase amber phase time
Retting, Ulmer & Williams, 1999	United States of America	Compared national fatality database and police crash reports	Definition: driver failed to obey a traffic signal 3% of all fatalities are due to red light running crashes Red light runners a more deviant population, more likely to be alcohol impaired, have invalid licenses and prior infringements Rec's: increased enforcement (red light cameras), increase amber phase time
Porter & England, 2000	United States of America	Manual observations	Definition: last driver to infringe at red light 35% of observed light cyclists had at least one red light runner May underestimate infringement rate, only one vehicle was recorded per light cycle Ethnicity is a predictor (non-Caucasian) Rec's: increased enforcement (red light cameras)

The study provides new, baseline data on the rate of urban cyclist red light infringement and identifies the cyclists' characteristics and key factors related to the behaviour. A manuscript of the red light infringement analysis was submitted to the journal *Accident Analysis and Prevention* in March 2010, peer-reviewed, revised and accepted for publication on August 2010 and published in January 2011 in Volume 43, Issue 1. The final published version of this journal paper is presented in Section 5.1.

Monash University

Declaration for Thesis Chapter 5

5.1 *Riding through red lights*

Declaration by candidate

In the case of the publication presented in Chapter 5, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
▪ Concept and design – initial concept, development of study design ▪ Acquisition of data – data collection, data management, supervision of data quality, operation of technical equipment ▪ Analysis and interpretation – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures/illustrations, revision/editing for intellectual content	80%

The following co-authors contributed to the work.

Name	Nature of contribution
Dr Stuart Newstead	▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content
Dr Judith Charlton Dr Jennie Oxley	▪ Concept and design – initial concept, development of study design, statistical concepts ▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content

[redacted]
Candidate's signature

20 May 2011
Date

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location: Monash University Accident Research Centre, Clayton campus

[redacted]

Dr Stuart Newstead

16/5/2011

Date

[redacted]

Dr [redacted] Charlton

19/5/11

Date

[redacted]

Dr Jennifer Oxley

16/5/11

Date

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Riding through red lights: The rate, characteristics and risk factors of non-compliant urban commuter cyclists

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ABSTRACT

This study determined the rate and associated factors of red light infringement among urban commuter cyclists. A cross-sectional observational study was conducted using a covert video camera to record cyclists at 10 sites across metropolitan Melbourne, Australia from October 2008 to April 2009. In total, 4225 cyclists faced a red light and 6.9% were non-compliant. The main predictive factor for infringement was direction of travel, cyclists turning left (traffic travels on the left-side in Australia) had 28.3 times the relative odds of infringement compared to cyclists who continued straight through the intersection. Presence of other road users had a deterrent effect with the odds of infringement lower when a vehicle travelling in the same direction was present (OR = 0.39, 95% CI 0.28–0.53) or when other cyclists were present (OR = 0.26, 95% CI 0.19–0.36). Findings suggest that some cyclists do not perceive turning left against a red signal to be unsafe and the opportunity to ride through the red light during low cross traffic times influences the likelihood of infringement.

1. Introduction

Crossing an intersection against a red light is one of the most overt illegal road user behaviours. Intuitively, red light infringement may contribute to cyclist-driver collisions as these crashes predominately occur at intersections (Watson and Cameron, 2006). However, while numerous studies have investigated driver and motorcyclist red light infringement (Retting et al., 1999; Porter and England, 2000; Green, 2003; Herbert Martinez and Porter, 2006) and pedestrians who jaywalk (Jason and Liotta, 1982; Kim et al., 2008), little research has examined the rate, characteristics or risk factors of cyclist red light non-compliance in Australia or internationally.

Riding through red lights is frequently cited as the cyclist behaviour that most annoys drivers and is perceived as typical behaviour (O'Brien et al., 2002; Kidder, 2005; Fincham, 2006). Observed rates of red light infringement in Melbourne have been reported at 7–9 per cent (Daff and Barton, 2005; Johnson et al., 2008). Daff and Barton observed cyclists' behaviour at sites before and after bicycle storage boxes were installed, however these authors provided no further information on how many cyclists were observed. Johnson et al. observed cyclists' behaviour at only two sites. Further research is needed to confirm that the findings from these studies are representative of red light compliance among urban commuters. In a cross-sectional survey of commuter cyclists in Brazil, the self-reported rate of red light non-compliance was 38.4% ($n = 1151$), however, the authors provide no detail of the non-compliant cyclists' characteristics and behaviour (Bacchieri et al., 2010).

Higher rates of non-compliance have been reported among bunch riders, formal or informal groups of cyclists who ride together in formation (O'Connor and Brown, 2007). A review of existing video footage was conducted, following a pedestrian fatality after a bunch of riders rode through a red light at a pedestrian crossing, found that non-compliance decreased from 46% of all red lights faced prior to the collision (2005) to zero following the collision (2007) (Johnson et al., 2009). Despite the reported improved behaviour, no further observations have been analysed to determine if the behaviour change is representative of all bunch riders or if compliance has been maintained. Further, it is unlikely these findings can be generalised to other types of cyclists.

Cyclist crash involvement as a result of red light non-compliance has been found to be low in the United Kingdom (1.8%, $n = 508$ Police reported collisions) (Lawson, 1991) and in Queensland, Australia (6%, $n = 199$ collisions) (Green, 2003), (6.5%, $n = 1214$ collisions) (Schramm et al., 2008). However, there are more subtle repercussions of cyclist non-compliance beyond their safety when crossing intersections and include the negative impact on driver attitudes towards cyclists (Basford et al., 2002). Further, driver attitudinal research has found that cyclist gender and clothing influence

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Fig. 1. Video camera box in position on a sign post.

drivers' perception of cyclist competency (Walker, 2007) and likelihood of road rule compliance (Basford et al., 2002).

The aim of this study was to establish the rate, characteristics and risk factors of commuter cyclists who rode through a red light at intersections in metropolitan Melbourne. The findings of this study will provide new information on non-compliant cyclists.

2. Methods

2.1. Research design

A cross-sectional observational study was conducted using a video camera (Sony DCR-SR62) placed inside a small grey box and attached to a roadside sign post that displayed parking time details (see Fig. 1). The covert camera position eliminated potential behavioural bias, as road users were unaware they were being observed. Ethics approval was obtained from the Monash University Human Research Ethics Committee.

2.2. Site observations

Observations of cyclists were made at 10 sites along the most frequently used on-road commuter routes in metropolitan Melbourne. All sites were within 5 km of the CBD, had two lanes of forward travel, four lanes of cross traffic, a pedestrian crossing and a tram line parallel to the right vehicular lane. Morning observation sites were in-bound and afternoon observation sites were out-bound. Site gradient was flat with the exception of the continuous site (type 3) which had one downhill (morning) and one uphill (afternoon) site.

Cyclist behaviour at three cycling facility types was observed (see Fig. 2). The first type, referred to as standard, is the most common configuration in Melbourne. Standard facilities had a bicycle storage box (also know as an advanced stop line or bike box) at the front of the left turning lane; the lane did not have a turn filter light and the midblock bike lane discontinued on approach to the intersection. Six sites with this facility were observed, three in the morning and three in the afternoon. The second type had a bicycle storage box in front of the centre lane; the left parallel lane was a dedicated turning lane for vehicles with a filter light and the midblock bike lane discontinued on approach to the intersection. Two sites with this facility were observed, one in the morning and one in the afternoon. The third type is an uncommon cycling facility in Melbourne and was a continuous green painted bike lane that continued parallel with the vehicular lane from midblock to the intersection. Two sites were observed with this facility, one in the morning and one in the afternoon.

Each observation was for 3 h, from either 7–10 AM or 4–7 PM over 6 non-consecutive days, resulting in 18 h of footage per site. As observations were conducted during peak travel times it was assumed that cyclists were commuters. It was not necessary to observe multiple approaches as peak flow of cyclists travelled in one direction. All observations were conducted during warmer months (October–April) and during daylight savings period. Observations were restricted by the weather. Days when the forecast temperature exceeded 35 °C or days with rain during the morning observation period were excluded to minimise potential biases, such as fewer cyclists and a higher proportion of male cyclists.

Manual analysis of the data is resource intensive and was limited by project funding. Given that there were a number of other research questions to be addressed using other aspects of the same data, a subset was selected for the purpose of this study. In total, three observations (9 h) per site were analysed, this length of footage was chosen to provide sufficient power to address the hypotheses set.

2.3. Participants

All road users who entered the site were video recorded. Included in the analysis were cyclists who travelled through the intersection on the road and included cyclists who approached the intersection via the footpath or pedestrian crossing. Cyclists who turned off the road and onto the footpath or pedestrian crossing and did not continue through the intersection were excluded from further analysis.

It is important to note that the observations are unlikely to be of unique cyclists. The sites were repeatedly observed over 6 days and it is likely that some cyclists were filmed on more than one observation session and possibly faced a red light on more than one occasion. The correlation between observations of the same cyclist could not be accounted for since it was not possible to reliably identify cyclists from the video footage in order to link multiple observations in the data. Consequently the statistical values quoted in the analysis results may be conservative.

2.4. Data analysis

The outcome measure was cyclist red light compliance (yes/no). In Australia, it is illegal to cross any intersection against a red signal and left turn on red is not permitted in the state of Victoria where the observations were conducted. Non-compliance was defined as crossing the intersection against a red light, as described in previous studies of driver behaviour (Lawson, 1991; Porter and England, 2000; Green, 2003). Cyclists who entered the intersection on a green or amber light were coded compliant, even if the light turned from amber to red during the crossing. Cyclists who entered the

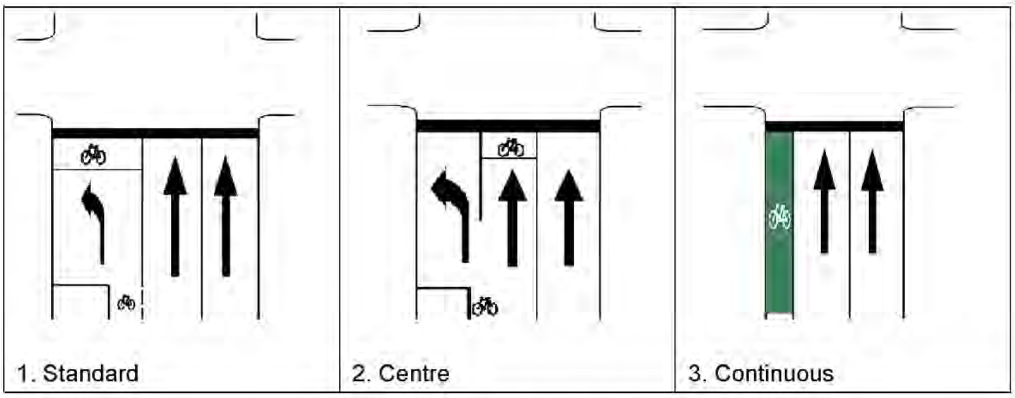

Fig. 2. Three cycling infrastructure types observed.

intersection but stopped and waited for the light to change to green or who made a 'rolling stop' but did not come to a complete stop were coded compliant. Cyclists who stopped but then 'jumped' the red light (Johnson et al., 2008) crossing before the light they were facing turned green, typically in the few seconds the cross light had changed to red, were coded non-compliant.

Given the binary outcome measure, a single binary logistic regression analysis model was used. The model included all available predictor variables and selected interactions simultaneously to determine the relationship between each predictor variable or interaction and the outcome measure along with the statistical significance of the measured associations. Since all factors were included in the model simultaneously each is automatically adjusted for confounding effects of the other predictor variables included in the model. All variables were treated as categorical variables in the model. The statistical analysis package SPSS 18.0 was used to calculate the descriptive statistics and construct the logistic regression models.

Three groups of predictor variables were recorded: location, cyclist characteristics, and other road users. The location variables and categories were time (AM or PM), gradient (flat, downhill or uphill) and cycling facility type (standard, centre, continuous).The cyclist variables and categories were: gender (male/female), bicycle type (road bike: drop handlebars; flat bar/mountain bike; other: included recumbent bikes, folding bikes and ladies bikes) and clothing (full cycling: jersey and cyclist pants; half cycling: either jersey or cyclist pants and; non-cycling: all other clothing which included sportswear, casual clothing and work attire), helmet use (yes/no), direction of travel (left/straight). None of the cyclists made a conventional right turn at the intersection from the right lane; rather they performed a right turn using a hook turn – that is, they first rode straight across the intersection and waited in front of the cross traffic lane for the cross flow traffic signal to turn green. The travel direction for these cyclists was coded as straight. The other road user variables and categories were: number of other cyclists (count), number of cross vehicles (count from left and right) and presence/absence of a vehicle at the intersection (yes/no). Cross traffic was defined as all vehicles that crossed the intersection from either direction from the time the cyclist came into view until the cyclist cleared the intersection. The traffic volume (count) was categorised (0, 1–10, 11–20, 21+). Vehicles in the same lane were vehicles at the intersection travelling in the same direction as the cyclists, at the standard and centre sites these vehicles were in the same lane as the cyclists and at the continuous facility sites the vehicle was in the adjacent lane.

Two logistic regression models were constructed. The first was conducted for all cyclists including all predictor main effects. A second analysis was conducted for male cyclists only and included a number of selected interactions. Since the majority of infringements were observed for male cyclists analysis of interactive effects between factors was only possible through restricting the analysis to male cyclists. To test for potential problems of co-linearity between predictor variables non-parametric correlations between all of the variables included in the model were examined. This analysis showed no evidence of co-linearity between any of the predictor factors. Subsequent cross-correlations between parameter estimates from the logistic regression models were examined confirming no problems of co-linearity between the factors.

Classification tables were used to assess the predictive power of the binary logistic regression models. A cut off of predicted probability of infringing of 0.07, the overall infringement rate in the study sample, was used as this yielded the highest sensitivity and specificity for the model.

To address potential coding bias, 10 h (11.5%) of footage was recoded by an independent research assistant and analysed using the Kappa statistic. The inter-rater reliability was Kappa = 0.688 ($p < 0.001$), 95% CI (0.472–0.904). This measurement of agreement is statistically significant and can be interpreted as substantial (Landis and Koch, 1977).

3. Results

A total of 4225 cyclists faced a red traffic light and 292 cyclists (6.9%) were non-compliant. The proportion of non-compliant cyclists varied across sites from 3.9% to 13.0%. No collisions were observed.

3.1. Descriptive statistics

The descriptive statistics for all cyclists were cross-tabulated with red light compliance (Yes/No) and are presented in Table 1.

Cyclists turning left had the highest proportion of infringement and this was higher among male cyclists (62.3%) than females (38.0%).

The types of bikes ridden and clothing worn were similar for male and female cyclists. The most observed bike type was mountain/flat bar (males: 68.5%, females: 82.1%) with more males riding road bikes (30.2%) than females (9.9%) and more females on 'other' bikes (8.1%) than males (1.3%). The majority of all cyclists wore non-cycling clothing (females: 84.5%, males: 65.0%). Males were more likely to wear full cycling clothing (24.1%) than females (6.7%) with a similar proportion wearing half cycling clothing (males: 11.0%, females: 8.8%).

Table 1
Observed variables for all cyclists by compliance (n = 4225).

	Compliance				
	Yes		No		Total
Time					
AM	1798	(94.1%)	112	(5.9%)	1910
PM	2135	(92.2%)	180	(7.8%)	2315
Gradient					
Flat	2900	(92.9%)	220	(7.1%)	3120
Downhill	367	(92.4%)	30	(7.6%)	397
Uphill	666	(94.1%)	42	(5.9%)	708
Facility					
Standard	2299	(93.1%)	170	(6.9%)	2469
Centre	601	(92.3%)	50	(7.7%)	651
Continuous	1033	(93.4%)	72	(6.5%)	1105
Gender					
Male	2871	(92.3%)	239	(7.7%)	3110
Female	1062	(95.2%)	53	(4.8%)	1115
Bike type					
Road	979	(93.3%)	70	(6.7%)	1049
Mountain/flat bar	2833	(93.0%)	213	(7.0%)	3046
Other	121	(93.1%)	9	(6.9%)	130
Clothing					
Full cycling	778	(94.5%)	45	(5.5%)	823
Half cycling	404	(91.8%)	36	(8.2%)	440
Non-cycling	2751	(92.9%)	211	(7.1%)	2962
Helmet					
No	7	(87.5%)	1	(12.5%)	8
Yes	3926	(93.1%)	291	(6.9%)	4217
Direction					
Straight	3872	(94.9%)	210	(5.1%)	4082
Left	61	(42.7%)	82	(57.3%)	143
Other cyclists present					
No	557	(80.0%)	139	(20.0%)	696
Yes	3376	(95.7%)	153	(4.3%)	3529
Cross traffic					
0	122	(50.6%)	119	(49.4%)	241
1–10	1174	(90.5%)	113	(9.5%)	1287
11–20	847	(95.9%)	36	(4.1%)	883
21+	1790	(98.7%)	24	(1.3%)	1814
Vehicle in lane					
No	1537	(89.4%)	183	(10.6%)	1720
Yes	2396	(95.6%)	109	(4.4%)	2505

3.2. Binary logistic regression – all cyclists

All factors were included in a binary logistic regression model, with non-compliance as the outcome variable (see Table 2). The overall predictive percentage of the model was 87.6%, sensitivity was 88.5% and specificity was 74.7%.

As demonstrated by the analyses reported above, direction of travel was associated with the highest likelihood of non-compliance. Cyclists turning left were 28.4 times more likely to infringe than cyclists riding straight. Gender was statistically significant: females had odds of infringement of 0.60 compared with males. Cycling facility was also statistically significant as cyclists at the centre facility had a 2.6 higher odds of infringement than cyclists at the standard facility site.

The presence of other road users had a deterrent effect; infringement was most likely when the cross traffic volume was low and decreased when cross traffic volume increased. When compared to cyclists at the intersection alone, odds of infringement were 0.39 compared when a driver was present and 0.26 when other cyclists were present.

Bike type and clothing were not significantly associated with infringement in the model at any level, despite high proportions in the descriptive statistics. Bicycle helmet use was high and while there is some suggestion that helmet use may be related to infringement odds, there were insufficient data to determine significance.

Table 2
Relative odds of infringement related factors in the model.

	Adj. Rel. odds of non-compliance	95% C.I. for odds	Statistical Sig.
Time			
PM vs AM	0.885	0.609–1.285	0.520
Gradient			0.902
Downhill vs flat	1.047	0.504–2.178	0.902
Facility			0.000
Centre vs standard	2.640	1.626–4.286	0.000
Continuous vs standard	1.305	0.780–2.181	0.310
Gender			
Female vs male	0.596	0.410–0.869	0.007
Bike type			0.385
Mountain/flat bar vs road	1.126	0.737–1.721	0.583
Other vs road	1.938	0.758–4.955	0.167
Clothing			0.226
Half cycling vs full cycling	1.657	0.906–3.029	0.101
Non-cycling vs full cycling	1.444	0.883–2.363	0.143
Helmet			
Not worn vs worn	0.205	0.021–2.029	0.176
Direction			
Left vs straight	28.399	17.770–45.386	0.000
Other cyclists present	0.260	0.189–0.359	0.000
Vehicle present	0.387	0.280–0.535	0.000
Cross traffic			0.000
1–10 vs 0	0.085	0.057–0.125	0.000
11–20 vs 0	0.035	0.021–0.059	0.000
21+ vs 0	0.014	0.008–0.024	0.000

3.3. Analysis of interactive effects

Additional logistic regression models were constructed to analyse interactions between all combinations of gender, bike type and clothing. None of the interactions tested were statistically significant. A systematic analysis of the interactions between male and female cyclists was also attempted however the model was nonconvergent due to too many empty cells. The problem with empty cells was caused by the generally low infringement rate for females and their relatively homogeneous choice of bike type. Given this limitation, the analysis was limited to male cyclists.

A second regression model was constructed using only male cyclists data to determine if male-specific interactions were evident. The bike type 'other' was also excluded due to insufficient observations. Findings were similar to those of the whole group, the only notable difference was that odds of infringement when turning left increased to 31.4 times more likely compared with travelling straight through the intersection. Interactions for bike type and clothing were not statistically significant ($p = 0.78$). Estimated odds for all other variables were not significantly different from the full sample.

4. Discussion

This study examined cyclist red light infringement, the rate and related factors and identified a number of behavioural and environmental predictors. Findings highlight that cyclists' propensity to ride through intersections against a red light as a multivariate issue.

Travel direction, specifically turning left, was the greatest predictor of infringement. Cyclists may perceive turning left to be a relatively safe manoeuvre since they are exposed to fewer points of conflict from cross traffic and cross traffic did have a deterrent effect and the perception of safety and opportunity to infringe decreased as the cross traffic volume increased (Wang and Nihan, 2004). However, despite the perceived safety associated with turning left against a red light, this manoeuvre may lead to an increased risk of cyclist-pedestrian collisions as was experienced in the United States of America when the right turn on red was introduced (Preusser et al., 1982). Further analysis is needed to determine the role of direction of cross vehicular traffic.

No collisions were observed. While this may suggest that noncompliance is a safe behaviour, collisions are relatively rare events. More importantly, the potential repercussions of this behaviour go beyond the individual cyclist. Cyclist red light non-compliance is the most frequently cited behaviour at annoys drivers (O'Brien et al., 2002; Kidder, 2005; Fincham, 2006) and there is potential that this annoyance may influence the attitudes and behaviours of some drivers when they interact with cyclists, beyond the individual non-compliant rider observed. In addition, unpredictability is a key concern of drivers when interacting with cyclists on the road (Basford et al., 2002) and cyclist red light non-compliance is likely to increase driver perceptions of unpredictability and reduce driver confidence when interacting with cyclists.

The presence of other road users, cyclists and drivers, travelling in the same direction had a deterrent effect on infringement. Other road users may be a proxy measure for high traffic periods or it may have a direct deterrent effect or other cyclists may speak to cyclists and admonish a non-compliant cyclist. Further investigation of cyclist attitudes is needed to understand the influence of others on red light non-compliance.

Despite drivers' perception that they can anticipate cyclists' behaviour based on appearance and bicycle type (Basford et al., 2002; Walker, 2007), this analysis found these characteristics had no predictive value on cyclists' likelihood of red light noncompliance.

Further, variations in non-compliance were also observed across the cycling facility types with cyclists more likely to be noncompliant at the centre sites than the standard or continuous sites. While there may be numerous reasons for this finding, for example differences in light phasing (left turn filter lights were available at the centre sites and not at other sites), or arrival time in the red light phase, these were not able to be determined from the observational data. More in-depth analysis is required to fully understand these contributing factors.

Finally, cyclists' non-compliance was deliberately not compared to driver behaviour as the opportunity to infringe is different. Any driver who may intend to infringe is restricted by the lead vehicle in the lane, therefore no following drivers have an opportunity to infringe. This is not the case for cyclists. Every cyclist is able to ride between waiting vehicles or cyclists and can choose to be noncompliant at almost every intersection. While it is likely that the predilection to infringe at red lights varies when people are cycling compared to driving, the opportunity to infringe is more comparable to pedestrians than drivers. Further analysis is planned to compare the rates of non-compliance between cyclists and pedestrians.

5. Strengths and limitations

This study determined the rate, characteristics and risk factors of commuter cyclists' red light infringement and provided an objective measure of actual cyclist behaviour and was not subject to behaviour modification or self-reporting bias. The multivariate analysis identified the impact of individual components on risk.

There were a number of study limitations. The infringement rate is not likely to be representative of all intersection types as observed sites had comparable traffic flow and complexity and are unlike less complex sites with no cross traffic (e.g. pedestrian crossings) or highly complex intersections with greater cross traffic volume. In addition, findings were for metropolitan commuter cyclists and may be comparable to cyclists in other urban areas however they may not represent non-urban riders or weekend behaviour.

Further, cyclist gender was determined by physical appearance and there is potential for some error in this subjective classification. It is also possible that factors that cannot be determined by observation, including age and socioeconomic factors, may contribute to the likelihood of non-compliance. Finally, cyclists are heterogeneous and findings may not relate to other types of riders.

6. Conclusion

The rate of red light non-compliance (7%) is lower than that found in previous studies have found and is not as widespread as reported in studies of drivers' perception. This study provides a baseline rate of red light non-compliance and establishes the types of behaviour that might be targeted for behavioural change countermeasures, such as turning left. Further research directions may include investigating the rate of red light infringement at various intersection types or among different cyclist types such as training riders, bicycle couriers, recreational riders or children. In addition, investigations into cyclist red light non-compliance may address: driver attitudes and perceptions and influences on driver behaviour; the mechanism of the deterrent role of other cyclists and vehicles and; cyclists' perceptions about the apparent safety of turning left and the potential implications on cyclist safety.

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References

Bacchieri, G., Barros, A.J.D., dos Santos, J.V., Gigante, D.P., 2010. Cycling to work in Brazil: users profile, risk behaviors, and traffic accident occurrence. Accident Analysis and Prevention 42 (4), 1025–1030.

Basford, L., Reid, S., Lester, T., Thomson, J., Tolmie, A., 2002. Drivers' Perceptions of Cyclists. Department for Transport, p. 42.

Daff, M., Barton, T., 2005. Marking Melbourne's Arterial Roads to Assist Cyclists. http://209.85.173.104/search?q=cache:OxpPBB8gK4AJ:www.ite.org/Conference/SamplePaper.pdf+%22Advanced+stop+lines+for+cyclists%22&hl=en&ct=clnk&cd=7&gl=us&client=firefox-a, viewed 10 July 2008.

Fincham, B., 2006. Bicycle messengers and the road to freedom. The Editorial Board of the Sociological Review, 209–222.

Green, F.K., 2003. Red light running. ARRB Transport Research Ltd., Vermont South.

Herbert Martinez, K.L., Porter, B.E., 2006. Characterizing red light runners following implementation of a photo enforcement program. Accident Analysis and Prevention 38 (5), 862–870.

Jason, L.A, Liotta, R., 1982. Pedestrian jaywalking under facilitating and nonfacilitating conditions. Journal of Applied Behavior Analysis 15 (469–473), 3.

Johnson, M, Charlton, J., Oxley, J., 2008. Cyclists and red lights—a study of the behaviour of commuter cyclist in Melbourne. In: Australasian Road Safety Research, Policing and Education Conference, Adelaide, 10–12 November.

Johnson, M., Oxley, J., Cameron, M., 2009. Cyclist Bunch Riding: A Review of the Literature. Monash University Accident Research Centre, Clayton.

Kidder, J., 2005. Style and action: a decoding of bike messenger symbols. Journal of Contemporary Ethnography 34 (2), 344–367.

Kim, K, Made Brunner, I., Yamashita, E., 2008. Modeling violation of Hawaii's crosswalk law. Accident Analysis and Prevention 40 (3), 894–904.

Landis, J.R, Koch, G.G., 1977. The measurement of observer agreement for categorical data. Biometrics 33 (1), 159–174.

Lawson, S.D., 1991. Red-light Running: Accidents and Surveillance Cameras. AA Foundation for Road Safety Research and Birmingham City Council, Birmingham.

O'Brien, S., Tay, R., Watson, B., 2002. An exploration of Australian driving anger. In: Road Safety Research, Policing and Education Conference, Adelaide, South Australia.

O'Connor, J.P., Brown, T.D., 2007. Real cyclists don't race: informal affiliations of the weekend warrior. International Review for the Sociology of Sport 42 (1), 83–97.

Porter, B.E, England, K.J., 2000. Predicting red-light running behavior: a traffic safety study in three urban settings. Journal of Safety Research 31 (1), 1–8.

Preusser, D.F, Leaf, W.A., DeBartolo, K.B., Blomberg, R.D., Levy, M.M., 1982. The effect of right-turn-on-red on pedestrian and bicyclist accidents. Journal of Safety Research 13 (2), 45–55.

Retting, R.A., Ulmer, R.G., Williams, A.F., 1999. Prevalence and characteristics of red light running crashes in the United States. Accident Analysis and Prevention 31 (6), 687–694.

Schramm, A., Rakotonirainy, A., Haworth, N., 2008. How much does disregard of road rules contribute to bicycle-vehicle collisions? In Proceedings High risk road users - motivating behaviour change: what works and what doesn't work? National Conference of the Australasian College of Road Safety and the Travelsafe Committee of the Queensland Parliament, Brisbane.

Walker, I, 2007. Drivers overtaking bicyclists: objective data on the effects of riding position, helmet use, vehicle type and apparent gender. Accident Analysis and Prevention 39 (2), 417–425.

Wang, Y, Nihan, N.L., 2004. Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections. Accident Analysis and Prevention 36 (3), 313–321.

Watson, L, Cameron, M., 2006. Bicycle and Motor Vehicle Crash Characteristics, Research Report, vol. 251. Monash University Accident Research Centre, Melbourne.

Chapter 6 Publication 2

Behaviour at cycling facilities at intersections

As discussed in the introduction to Chapter 5, the extensive video footage from Stage 1 provided detailed data and the opportunity for in-depth analysis of specific behaviours. In selecting the observational sites, intersections with different cycling facilities were deliberately selected as it was anticipated that there would be variations in cyclist and driver behaviours. The behaviours of cyclists and drivers, focusing on their compliance at the cycling facilities were the focus of the second publication.

It is important to understand how the cycling facilities were used, as according to the Victorian government road authority, VicRoads, dedicated space for cyclists increases cyclist safety, improves traffic flow and the performance of the road (VicRoads, 2001). However, the facilities are generally only effective in increasing cyclist safety if road users, both cyclists and drivers, use the facilities appropriately. In particular, it is important that drivers are compliant at cycling facilities if the lines are to create a safe space for cyclists on the road.

Previous research into bike boxes at intersections has focused on driver compliance during the red light phase. Driver compliance was defined as keeping the bike box clear and cyclist compliance was defined as entering the bike box when available (Hunter, 2000; Newman, 2002; Allen et al., 2005). Reduction in cyclist-driver collisions have been reported following the installation of bike boxes (Newman, 2002), however negative responses and behaviours have also been reported with high levels of driver encroachment into the bike box, even when a cyclist was present (Hunter, 2000; Allen et al., 2005).

It was noted in the pilot study, that drivers appeared to be less compliant than cyclists at cycling facilities at intersections; however this was not quantified in the pilot study analysis. The aim of the publication presented in this chapter was to evaluate cyclist and driver compliance at different cycling facilities in Melbourne and to address the following doctoral research question:

- *What is the role of cycling infrastructure/facilities in cyclist-driver interaction and behaviour?*

Publication 2

In the publication, a total of 54 hours of footage was analysed. The analysis included footage from 6 sites, 3 morning sites and 3 afternoon sites, and 3 observations (i.e. 9 hours) for each site. The sites observed were 1, 2, 3, 4, 7 and 8 according to Table 4-2. The three different cycling facilities were included: standard, centre and continuous.

In total, 2,670 cyclists and 1,243 drivers were observed at the cycling facility during the red light phase. Both cyclists and drivers were more compliant at the continuous sites than the standard or centre sites. However, at the bike box sites, cyclists were more compliant (60.4%) than drivers (49.6%). It is possible that the placement of the bike boxes may contribute to the lower rates of driver compliance. The need for greater education of cyclists and drivers about the function and importance of these bike boxes is discussed.

The study provides new data on how cyclists and drivers use cycling facilities at intersections and identifies the variation in behaviour in relation to the presence of other road users. A manuscript of the behaviours at cycling facilities at intersections was submitted to the *Journal of the Australian College of Road Safety* in April 2010, peer-reviewed, revised and accepted for publication in May 2010. The paper was published in a special cycling research edition of the journal in August 2010. The final published version of the journal paper is presented in Section 6.1.

Monash University

Declaration for Thesis Chapter 6

6.1 *Cyclist and driver behaviour at cycling facilities at intersections*

Declaration by candidate

In the case of the publication presented in Chapter 6, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
▪ Concept and design – initial concept, development of study design ▪ Acquisition of data – data collection, data management, supervision of data quality, operation of technical equipment ▪ Analysis and interpretation – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures/illustrations, revision/editing for intellectual content	80%

The following co-authors contributed to the work.

Name	Nature of contribution
Dr Judith Charlton	▪ Concept and design – initial concept, development of study design, statistical concepts ▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content
Dr Stuart Newstead	▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content
Dr Jennie Oxley	▪ Concept and design – initial concept, development of study design, statistical concepts ▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content

[redacted]

Candidate's signature

20 May 2011

Date

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location: Monash University Accident Research Centre, Clayton campus

[redacted] 19/5/11

Dr [redacted]h Charlton Date

[redacted] 16/5/2011

Dr Stuart Newstead Date

[redacted] 16/5/11

Dr Jennifer Oxley Date

Journal of the Australasian College of Road Safety – August 2010

Painting a designated space: Cyclist and driver compliance at cycling infrastructure at intersections

by Marilyn Johnson, Judith Charlton, Stuart Newstead and Jennifer Oxley, Monash University Accident Research Centre, Monash University, Clayton, Victoria

Abstract

This study evaluated cyclist and driver compliance at cycling infrastructure at signalised intersections to determine the effectiveness of the infrastructure in creating a designated space for cyclists. A cross-sectional observational study was conducted during peak travel times at six sites in Melbourne in March 2009. Three types of infrastructure were observed: 1) bicycle storage box in front of left lane, 2) bicycle storage box in front of centre lane and 3) continuous green-painted bicycle lane. Two sites were observed for each infrastructure type, one morning and one early evening. A covert fixed position video camera was used to film all road users, and the behaviour of cyclists and drivers who stopped at the intersection during the red light phase was coded. In total, 2670 cyclists and 1243 vehicles were observed. Compliance was highest at the continuous bicycle lane sites for cyclists (95.4%) and drivers (97.7%). At bicycle storage box sites, cyclists (60.4%) were more compliant than drivers (49.6%). The placement of bicycle storage boxes may contribute to lower rates of driver compliance and cyclists' perceptions of safety and subsequently cyclist compliance. Driver and cyclist education campaigns may increase compliance.

Keywords

Cycling infrastructure, Driver compliance, Cyclist compliance, Bicycle storage box

Introduction

On-road cycling infrastructure is designed to create designated spaces for cyclists. Recent studies suggest that treatments give drivers confidence about interacting with cyclists [1], cyclists prefer routes with cycling infrastructure [2-4] and report feeling safer [5,6]. However, for the infrastructure to be effective, drivers and cyclists need to be compliant, and there has been little research into how cyclists and drivers use these spaces and whether the infrastructure creates a clear space for cyclists on the road.

The number of people cycling in Australia is increasing [7] and so too is the introduction of cycling infrastructure. During the last decade in metropolitan Melbourne, for example, there has been a substantial increase in the installation of cycling facilities in an effort to improve the overall safety of cyclists, increase their visibility and legitimacy, and improve traffic flow [8]. The principal bicycle network currently has 1200km of completed on-road and off-road cycling routes [9]. The most common bicycle infrastructure implemented in Victoria is a bicycle lane, typically a painted white line with a painted bicycle symbol along the left side of the kerbside lane. In some locations across Melbourne, the bicycle lanes are painted green to increase driver and cyclist awareness of the lane particularly, at busy or complex locations [10].

While cycle lanes are effective in providing separation of cyclists and vehicles, one of the major disadvantages is that they inevitably cross roads at various points, and interaction with vehicular traffic at intersections places cyclists at heightened risk. In many cases, bicycle lanes discontinue on approach to intersections. Indeed, along Melbourne's most used on-road commuter cyclist route, St Kilda Road, most mid-block bicycle lanes discontinue on approach to the intersection, and cycling infrastructure is absent from the holding area and through the intersection.

In some locations a bicycle storage box (see description in next paragraph) is provided at the intersection bar. According to the Australian and Victorian traffic engineering guidelines, at points where the road narrows, cyclists are expected to defend their space among moving vehicular traffic by positioning themselves in the centre of the lane [11] as the priority for space allocation on the roads is to vehicles [12]. However, where there are feeder lanes into the bicycle storage box, cyclist behaviour has been found to be more predictable than when the bicycle lane discontinues [13].

Bicycle storage boxes have been widely installed in Melbourne. Also called advanced stop lines or head start areas, bicycle boxes originated in the Netherlands. They are painted on the road at the front of the vehicular traffic lane at intersections and aim to create a separate space for cyclists to wait during the red light phase. The position increases driver awareness of the cyclist, thus increasing cyclist safety [6, 14].

Cycling infrastructure research in New Zealand identified the primary objectives of the boxes were to improve cyclists' physical safety and reduce cyclists' perceived risk at intersections. The study found a reduction in driver-cyclist collisions after the installation of the box, and cyclists reported feeling safer. However, the authors reported that drivers did not like cyclists 'stacking' ahead of them and felt unsure or non-committal about the purpose and function of the box [15].

In Victoria, an additional intention of the boxes was to formalise, and in doing so legitimise, the informal behaviour of cyclists of rolling through to the front of traffic during the red light phase [16]. In addition, the boxes have the advantage of locating cyclists away from vehicle exhausts while waiting in traffic, and provide an opportunity for them to leave from the traffic lights first, ahead of vehicular traffic [12, 17].

For the bicycle storage box to be effective, the space must be kept clear for cyclists. Several studies have found that vehicle encroachment during the red light phase has created concern for cyclists. Newman found that driver intrusion did influence cyclist confidence and their position at the intersection. In video observations, cyclists were likely to use the box, whereas drivers were the least compliant and intruded on or obscured the cycling infrastructure [15]. A before-and-after observational study of bike storage box installations in the United States found that slightly more than half the vehicles observed (51.9%) encroached into the box [17]. In the United Kingdom, of 5114 cyclists observed, 36% experienced a vehicle encroaching into the bike storage box [13].

Driver and cyclist education about how to interact with the cycling infrastructure also influence compliance [13, 15, 17]. In Victoria, the current graduated licensing system is underpinned by the Victoria drivers licence handbook Road to Solo Driving. There are numerous references to bicycle lanes and appropriate driving behaviour when sharing the road with cyclists. However, there is limited information on broader cycling infrastructure, with only one reference made to bicycle storage boxes, referred to as 'head start' areas, with no information about appropriate driver behaviour at a bicycle storage box [18].

More extensive information about driver and cyclist behaviour, including an increase of penalties for encroaching into a bicycle storage box, has been available on the VicRoads website since changes to the Victorian road rules in November 2009. Drivers may be fined up to 10 penalty points (currently $1168.20) [19, 20]. There are detailed instructions about the correct positioning of drivers and cyclists on the road with a clear, instructive animated graphic. However, this information is located on a cyclist-specific road rule site, and it is not known how many non-cycling drivers view this page.

The aim of this study was to evaluate cyclist and driver compliance at different cycling infrastructure treatments at signalised intersections. Given the increasing number of cyclists in Australia and the lack of research focused on the safety implications of cycling infrastructure, it was anticipated that the findings would contribute to knowledge about infrastructure use and highlight potential solutions to improve cyclist safety.

Methods

This study was designed to assess the compliance of cyclists and drivers at signalled intersections with varied cycling infrastructure. The observation sites included three types of cycling infrastructure that have been implemented along the most frequently used on-road cyclist commuter routes in metropolitan Melbourne. A novel covert position was used to record the behaviours of all cyclists and drivers who entered the sites.

Research design

This was a cross-sectional observational study of on-road commuter cyclists. The study was conducted in March 2009 at six sites along popular on-road commuter cyclist routes on St Kilda Road and Swanston Street [21]. All sites were within five kilometres of the central business district (CBD), as measured from the Melbourne Town Hall. Each observation was a three-hour recording repeated over six non-consecutive days either at 7-10am or 4-7pm, resulting in 18 hours of recordings per site. Given the time of the observations, it was assumed that most cyclists and drivers were commuting to or from work. It was not necessary to observe multiple approaches, as the peak flow of commuter cyclists travelled in one direction at all observed sites.

Observation sites

Three types of cycling infrastructure at intersections were observed: a bicycle storage box in front of the left lane, a bicycle storage box in front of the centre lane and continuous green-painted bike lane. As the majority of the cyclist traffic flow is one way during peak hour travel times, only one approach was observed at each site. The three treatment types are illustrated in Figure 1.

Bicycle storage box in front of the left lane

Intersections with bicycle storage boxes in front of the left lane (Figure 1, diagram 1) were observed at two intersections on the most used on-road cycling commuter route in Melbourne, along St Kilda Road from the south-eastern suburbs of Melbourne [21]. Two sites were observed, one in the morning (in-bound) and one in the afternoon (out-bound). The signals at this intersection did not have a left-turn filter light. This is the most common bicycle storage box position along the selected route.

Bicycle storage box in front of the centre lane

The second type of bicycle storage box (Figure 1, diagram 2) was also observed along St Kilda Road, and at these sites the bicycle storage box was located in front of the centre vehicular lane. The intersections with this infrastructure had a dedicated left-turn vehicle lane with a left turn filter light. The position of the centre storage box placed cyclists ahead of drivers who were continuing straight through the intersection.

For all bicycle storage box sites observed, there was no bike lane on the approach to the intersection. The mid-block bike lane discontinued prior to each observed site.

Continuous bicycle lane

The third type was green-painted bicycle lanes that continued from midblock to the intersection; the lane did not continue through the intersection, as shown in Figure 1 (diagram 3). These sites were located along Swanston Street to the north of the CBD. The lanes were located kerbside, parallel to the vehicular traffic, and were continuous with the mid-block Copenhagen-style bike lane. These sites did not have a bicycle storage box at the intersections.

Procedures

A Sony DCR-SR62 video camera was positioned inside a small grey box and attached to a roadside sign post that gazetted parking time details. The camera position recorded the behaviours of all road users who entered the space, and continuous recording allowed detailed analysis of cyclist and driver behaviours. The covert positioning of the camera eliminated potential behavioural bias, as cyclists and drivers were unaware they were being filmed.

There were weather-related restrictions to the observations to minimise potential bias. Observations were not conducted on days over 35°C or when it rained during the morning observation period, as on these days there were lower numbers of cyclists and fewer female cyclists. Observations continued on the next suitable day.

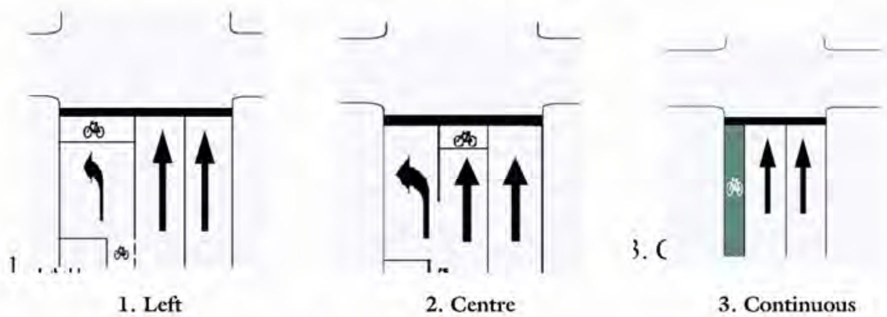

Figure 1. Cycling infrastructure observed

Definitions of cyclist and driver compliance

Of interest was cyclist and driver compliance at the cycling infrastructure types when approaching a red light. At the bicycle storage boxes, cyclist compliance was defined as entering the bike storage box with at least one wheel in the box. For drivers, compliance was defined as stopping before the bicycle storage box, defined as the front wheels of the vehicle stopping before the white line of the box. It was possible that there may still be vehicle encroachment, with the bonnet of the vehicle entering the bicycle storage box; however, given the perspective recorded by the camera, the wheel-based classification was the only objective classification possible across all the sites. Only the first vehicle to approach the intersection was coded at all sites. Non-compliance was recorded when the wheels encroached into the box.

At the continuous bicycle lane, cyclist compliance was defined as staying within the bicycle lane. Cyclists who stopped in front of the continuous bicycle lane (i.e., in the pedestrian crossing or in the parallel vehicle lane) were coded as non-compliant. For drivers, compliance was defined as stopping parallel, with all wheels outside the bicycle lane. Drivers whose vehicle wheels encroached into the bicycle lane were coded non-compliant. It is possible that vehicle protrusions or mirrors may have entered the bicycle lane.

There is potential for coding bias in observational studies, particularly with a single researcher coding the data. In this study, compliance for both cyclists and drivers was coded separately by an independent research assistant for 6 hours (11.1%) of footage and analysed using the Kappa statistic. The inter-rater reliability was Kappa = 0.673 ($p<0.001$), 95% CI (0.585-0.761). This measurement of agreement is statistically significant and can be interpreted as substantial [22].

Results

Nine hours of footage was analysed for each of the six sites, for a total of 54 hours. A total of 2670 cyclists (including 1878 males and 792 females) and 1243 vehicles stopped at the intersection at the observation sites during the red light phase.

Descriptive statistics

Cyclist and driver compliance rates were cross-tabulated with the three cycling infrastructure types as summarised in Table 1.

Compliance was greatest at the continuous lane location, with a high level of compliance by drivers and cyclists. In comparison, cyclists were more compliant than drivers at the bicycle storage box sites, regardless of the positioning of the box. Across the infrastructure types, the relative compliance was different for cyclists and drivers ($\chi_2^2 = 16.217$, $p<0.001$).

Binary logistic regression – cyclists

Site infrastructure type, time of day and cyclist gender were included in a binary logistic regression with compliance (yes/no) as the outcome variable (see Table 2). A cut-off for predicted probability of compliance of 0.07 was used in the classification tables for the fitted model. The overall correct predictive percentage of the model was 67.4%, with sensitivity 63.8% and specificity 78.1%.

Infrastructure type had the strongest association with cyclist compliance. In particular, the compliance odds at the continuous bicycle lane was 12.4 times the compliance odds at the left bicycle storage box infrastructure. There was also an association with time of day and compliance odds, with the compliance odds 39.3% less in the afternoon compared with the morning. There was no statistically significant association between compliance and gender.

Table 1. Descriptive statistics of cyclist and driver compliance at three cycling infrastructure types

	Cyclists		Drivers	
	% compliant	Observed	% compliant	Observed
Infrastructure				
Left bicycle storage box	64.9%	1005	49.8%	275
Centre bicycle storage box	53.0%	614	49.6%	516
Continuous bicycle lane (green)	95.4%	1051	97.7%	452

Table 2. Relative odds of compliance-related factors in the model - Cyclists

		Relative odds of compliance	Statistical significance	95% C.I. for odds	
Infrastructure			0.000		
Infrastructure	Centre vs left	0.686	0.000	0.556	0.848
Infrastructure	Continuous vs left	12.494	0.000	9.059	17.230
Time	pm vs am	0.607	0.005	0.496	0.744
Gender	Female vs male	0.926	0.478	0.749	1.145

Binary logistic regression – drivers

A second binary logistic regression was constructed for drivers, including infrastructure and time of day, with compliance as the outcome variable (see Table 3). A cut-off for predicted probability of compliance of 0.07 was used in the classification tables for the fitted model. The overall correct predictive percentage of the model was 67.6%, with sensitivity 52.9% and specificity 97.5%.

Again, infrastructure type had the strongest association with driver compliance. In particular, the compliance odds at the continuous bicycle lane were 43.9 times the compliance odds at the left bicycle storage box infrastructure. The time of day and compliance association was similar to the cyclist rate, with drivers having an odds of compliance 32.0% lower in the afternoon compared with the morning.

Discussion

Common cycling facilities such as bicycle lanes and bicycle storage boxes aim to separate cyclists and vehicles along mid-block and at critical locations; however, such infrastructure treatments are only effective if they result in appropriate behaviour. While there are some noted benefits of these treatments, little is known about their effect on behaviour. This study examined cyclist and driver compliance behaviour at three types of cycling infrastructure at signalled intersections.

Infrastructure type was the greatest predictor of compliance. Specifically, the continuous, green bicycle lane was associated with the highest levels of compliance by both groups of road users. A key point to note is that compliance creates different demands depending on the infrastructure type. The continuous bicycle lane was a continuation of the mid-block infrastructure, so drivers and cyclists continued to travel parallel with each other to the intersection. The only compliance requirements were that drivers did not encroach on the green lane when they turned left and cyclists maintained their position within the lane.

However, at the bicycle storage box sites, compliance does require a variation in travel behaviour between mid-block and intersection. Firstly, while drivers and cyclists travel in parallel when mid-block, compliance at the bicycle storage box requires drivers to stop behind the box, short of their 'usual' position at the intersection. Secondly, cyclists are required to move from travelling in parallel to the drivers to stop in front of the vehicle. This need for variation in behaviour may have contributed to non-compliance, and it may be that cyclist infrastructure is perceived as less legitimate when it displaces drivers.

The continuous bike lane was painted green at both observed sites, so it is not possible to determine whether it was the continuous path or the painted colour or a combination of both elements that contributed more directly to higher compliance. The importance of colour to distinguish cycling infrastructure and discourage vehicle encroachment has also been identified at bicycle storage boxes [11,17]. Further research is needed to determine the role of coloured surface treatments for cyclist infrastructure and both cyclist and driver compliance.

At all bicycle storage box sites, the level of compliance of cyclists was higher than drivers. This may suggest that a high proportion of compliant cyclists perceived the boxes to provide a safe space to wait during the red light phase. It is not known why approximately half of drivers were non-compliant. Possible reasons may be lack of knowledge of the purpose of the boxes, disregard for the space if no cyclists are already present, failure to notice the infrastructure or acknowledge the space as legitimate, or failure to accept cyclists as legitimate road users. Further research is needed to determine the reasons for driver non-compliance. Time of day was a significant factor for both cyclists and drivers, as groups were more compliant in the mornings than the afternoons.

At the centre bicycle storage box sites, some cyclists were coded as non-compliant because they stopped behind the bicycle storage box in single file along the left side of the waiting vehicle, rather than in front, essentially creating an informal left-side bike lane. Further research is needed to determine cyclists' motivations for this behaviour; possible motivations may include perception of safety, habit, lack of awareness of the function of the box or reluctance to impede drivers. Further research is also needed to determine the role of vehicle positioning on cyclists' non-compliance.

In order to improve compliance we need a better understanding of the influencing factors. Recent changes to Victorian road rules increased the penalty for non-compliant drivers at bicycle storage boxes; however, there have been limited education and awareness campaigns about the changes, and to date the impact of the road rule changes on compliance is not known. It is likely that education and awareness programs that inform all road users of the function of the space will improve compliance.

Table 3. Relative odds of compliance related factors in the model – Drivers

		Relative odds of compliance	Statistical significance	95% C.I. for odds	
Infrastructure			0.000		
Infrastructure	Centre vs left	0.956	0.767	0.712	1.285
Infrastructure	Continuous vs left	43.866	0.000	22.436	85.766
Time	pm vs am	0.680	0.006	0.517	0.895

Compliance may be affected by additional factors such as vehicle type or the presence of other road users, and therefore available space, on arrival. This could be addressed with further analysis of the video observations. It is also possible that non-observable factors may also contribute to compliance, such as socio-economic status of the cyclist or driver, or perceptions of safety. Survey research is planned to explore these factors further.

Conclusion

This study has provided a baseline measure of cyclist and driver compliance for three commonly used cycling infrastructure treatments. Highest compliance rates for both cyclists and drivers were observed for continuous bike lanes and during morning observation times. It is recommended that future research be conducted to identify reasons for non-compliance and to explore potential treatments to enhance compliance, including coloured bicycle storage boxes and continuous bicycle lanes.

Acknowledgements and declaration

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References

1 Basford L et al. Drivers' perceptions of cyclists. Department for Transport, 2002, 42
2 Garrard J, Crawford S, Hakman N. Revolutions for women: Increasing women's participation in cycling for recreation and transport. Burwood: Deakin University, 2006
3 Krizek KJ, Roland RW. What is at the end of the road? Understanding discontinuities of on-street bicycle lanes in urban settings. Transportation Research Part D, 2005; 10: 55-68
4 Dill J, Carr T. Bicycle commuting and facilities in major U.S. cities: If you build them, commuters will use them. Transportation Research Record, 2003; 1828: 116-23
5 Davies D. et al. Attitudes to cycling. A qualitative study and conceptual framework. Transport Research Laboratory, 1997
6 McClintock H, Cleary J. Cycle facilities and cyclists' safety: Experience from Greater Nottingham and lessons for future cycling provision. Transport Policy, 1996; 3(1-2): 67-77
7 Department of Communications, Information Technology and the Arts. Participation in exercise, recreation and sport annual report 2007. DCITA, 2008
8 VicRoads. Creating on-road space for cyclists. Cycle Notes No. 9, 2001.
9 VicRoads. Principal Bicycle Network (PBN). 2010. http://www.vicroads.vic.gov.au/Home/Moreinfoandservices/Bicycles/StrategicDirectionsForCycling/BicycleNetworkPlanning/PrincipalBicycleNetwork.htm. (Accessed 10 March 2010)
10 VicRoads. Coloured surface treatments for bicycle lanes. Cycle Notes No. 14, 2005
11 Austroads. Guide to traffic engineering practice: Bicycles. Part 14. Sydney: Austroads, 1999
12 VicRoads. 'Head start' storage areas at intersections. Cycle Notes No. 5, 2000.
13 Allen D, Bygrave S, Harper H. Behaviour at cycle advanced stop lines. Transport Research Laboratory, 2005
14 Pucher J, Dill J, Handy S. Infrastructure, programs, and policies to increase bicycling: An international review. Preventive Medicine, 2010; 50(Supplement 1): S106-S125
15 Newman A. The marking of advanced cycle lanes and advanced stop boxes at signalised intersections. Christchurch. 2002
16 Daff M, Barton T. Marking Melbourne's arterial roads to assist cyclists. 2005. http://209.85.173.104/search?q=cache:OxpPBB8gK4AJ:www.ite.org/Conference/SamplePaper.pdf+%22Advanced+stop+lines+for+cyclists%22&hl=en&ct=clnk&cd=7&gl=us&client=firefox-a
17 Hunter WW. Evaluation of a combined bicycle lane/right turn lane in Eugene, Oregon. University of North Carolina, Chapel Hill, Federal Highway Administration, 2000, 19
18 VicRoads. Road to solo driving: Learning to drive, driving to learn. Kew, Victoria: Roads Corporation Victoria, 2007
19 Victoria Legal Aid. Stopping at traffic lights where there are bicycle boxes. 2009. http://www.legalaid.vic.gov.au/2642.htm. (Accessed 17 February 2010)
20 Victoria Legal Aid. Penalty and fee units. 2009. http://www.legalaid.vic.gov.au/1700.htm. (Accessed 17 February 2010)
21 City of Melbourne. Melbourne bicycle account – A cycling census 2008. Melbourne: City of Melbourne, 2008
22 Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics, 1977; 33: 159-74

Chapter 7 Publication 3

Naturalistic cycling study – pilot study

The Stage 1 observational study was successful in providing new insights into the behaviours of cyclists and drivers, how they interact and the variations in behaviour at different cycling facilities. The footage of thousands of cyclists and drivers is a detailed dataset that can be repeatedly reviewed and further analysis is likely to provide even more information about factors that may affect cyclist safety. However, this focused and detailed view was also a limitation, as the fixed observations only provided data on the activities that occurred at these particular locations, inside the 'window of observation' (Gomm, 2004: 222).

One of the doctoral research questions was to identify pre-event factors that contribute to cyclist-driver collision and near-collision events. This research question was not addressed in the Stage 1 observational study, as discussed in Chapter 5, no collision or near-collision events were filmed in the Stage 1 observational study. Therefore in Stage 2, the objective was to widen the range of cyclist experiences observed, in an attempt to capture and analyse collision and/or near-collision events. This expanded approach also needed to include cyclist and driver behaviours and interactions across the entire road network. A new method was required for this undertaking and this was achieved by conducting a naturalistic cycling study.

The naturalistic cycling study undertaken in Stage 2 of this doctoral research was modelled on the first comprehensive, in-depth naturalistic driving study, the 100-Car Study. Conducted at the Virginia Technology Transportation Institute, the study involved 100 cars that were each fitted with 5 video cameras that filmed activities inside and outside the vehicles for one year (Neale et al., 2002; Neale et al., 2005; Dingus, Klauer, Neale, Petersen, Lee et al., 2006). Importantly, the research team developed an extensive data dictionary that was used to analyse recorded collision or near-collision events. The data dictionary consisted of descriptive definitions for use in coding over 30 factors in an event. Examples of the factors include: event severity, environmental factors, pre-event and post-event behaviours of the participant driver and other road users (Dingus et al., 2006).

The naturalistic cycling study was conducted by attaching a small compact video camera to the helmets of commuter cyclists and recording their trips to and from work. The benefits of using a helmet mounted camera, or point of view (POV) camera to understand the cyclist's experience have been reported in previous studies as discussed in Chapter 2. As discussed in the literature review in Chapter 2, no published studies were found of helmet cameras being used to systematically analyse on-road cyclist-driver interactions to understand the factors that contribute to collisions and near-collisions. It was anticipated that such an approach would provide important insights into pre-event factors and a new methodology needed to be developed. The development of a methodology and data analysis technique was the focus of the first phase in Stage 2 of this doctoral research.

The process of adapting the 100-car study methodology for use with cyclists was the focus of the third publication. The dictionary was adapted and modified, primarily shifting the focus from the driver's experience to the cyclist's experience. This involved removing the factors related to the internal cameras used in the 100-car study as only one forward facing camera was used in this research. Modifications were also made to reflect that Australian road users travel on the left side of the road. Cyclist specific factors were also added including head check and cycling facilities. The doctoral research question that was addressed in this publication was:

- *What contributing factors can be identified in cyclist-driver collision and near collision events?*

Publication 3

The third publication describes the adaptation of a naturalistic driving study approach to cyclists and includes data from a pilot study of six cyclists. The pilot naturalistic cycling study was conducted from March to May 2009. The initial challenges in developing this method were twofold. First, were the practical concerns regarding how to attach a camera to the participant's helmet that would be secure for a four-week period. The attachment mechanism needed to be secure enough to ensure the camera stayed in the correct position for the study duration but not damage the helmet on removal. Second, it was necessary to establish the feasibility of the 100-car study data dictionary for analysis of footage recorded by the participants. To address these challenges a pilot study was conducted.

A manuscript of the adaptation and pilot study was submitted for presentation at the Australian Cycling Conference in Adelaide, South Australia, 18-19 January 2010. The paper was peer-reviewed, revised and accepted to the conference. The paper was also selected for inclusion in the journal *Road and Transport Research* in a special cycling edition of the journal and was published in June 2010 in Volume 9, Number 2. The final published version is presented in Section 7.1.

Monash University

Declaration for Thesis Chapter 7

7.1 Naturalistic cycling study – pilot study

Declaration by candidate

In the case of the publication presented in Chapter 7, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
▪ Concept and design – initial concept, development of study design ▪ Acquisition of data – data collection, data management, supervision of data quality, operation of technical equipment ▪ Analysis and interpretation – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures/illustrations, revision/editing for intellectual content	80%

The following co-authors contributed to the work.

Name	Nature of contribution
Dr Judith Charlton Dr Jennie Oxley	▪ Concept and design – initial concept, development of study design, statistical concepts ▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content

[redacted]

Candidate's signature

20 May 2011

Date

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location: Monash University Accident Research Centre, Clayton campus

[redacted]

Dr Judith Char[redacted] 19/5/11

Date

[redacted]

Dr Jennifer Oxley 16/5/11

Date

The application of a naturalistic driving method to investigate on-road cyclist behaviour: A feasibility study

Marilyn Johnson, Judith Charlton and Jennie Oxley

Refereed Paper

This paper is based on a presentation to the Australian Cycling Conference in Adelaide, January 2010. It has been critically reviewed by at least two recognised experts in the field prior to publication here.

Originally submitted: March 2010.

Abstract

Background: The aim was to develop a naturalistic cycling method using a helmet-mounted video camera to investigate the behaviour of on-road commuter cyclists and their interactions with other road users in urban areas. Cycling is increasing in popularity popular in Australia; however, cyclists are physically vulnerable road users. To date, there has been little research on behavioural risk factors associated with collisions between cyclists and drivers, and much has relied on post-event data. Absent from this approach is an understanding of what contributed to collisions and near-collisions, in particular the behaviour of cyclists and drivers.

Method: The technique used in this pilot study to examine commuter cyclists' riding experiences during regular trips was based on the 100-Car Naturalistic Driving Study and used helmet-mounted video cameras to capture footage representing the cyclists' view. Six participants each recorded 12 hours of cycling footage. Participants also completed a pre-study questionnaire, provided weekly updates and a semi-structured exit interview.

Data: The video footage was reviewed and low-light footage and footage of time spent riding off road were excluded. In total, 46 hours and 16 minutes of footage were reviewed, no crashes were recorded and 36 other event types were identified for further analysis. The 100-car study data dictionary of variables was modified to analyse the current data, including changing the referent from driver to cyclist, two cycling-specific variables were developed (head checks and cycling facility). Descriptors related to driving behaviours and internal vehicle cameras were excluded. In addition, the VicRoads Definitions for Classifying Accidents was used to classify events.

Conclusion: With modification, the naturalistic driving method was successfully adapted to

investigate the experiences and behaviour of on-road cyclists. One of the strengths of this method is the continuous recording that allows repeated, detailed review and analysis of events over the entire trip including pre near-collision risk factors. A large-scale study using this method is planned that is expected to provide insights into the causal and contributing factors involved in near-collisions and potential collisions between cyclists and drivers.

INTRODUCTION

The number of people cycling in Australia is increasing. Cycling participation, defined as cycling at least once a week, has increased by 11% from 2001 to 2007 (Department of Communications Information Technology and the Arts 2008), but little is known about the behaviours of cyclists and drivers or the characteristics of collisions and near-collisions involving cyclists. Additional information is needed to determine the cause of the incidents and in turn how the number and severity of collisions may be reduced.

Previous research into risk factors associated with cyclist–driver collisions has focused on post-event data including official records (Australian Transport Safety Bureau 2006; Watson and Cameron 2006) and self-reported questionnaires (Aultman-Hall and Hall 1998; Rivara et al. 1997), and fixed-point observations have been limited to a single site (Daff and Barton 2005; Harkey and Carter 2006; Johnson et al. 2008). Extensive analyses of hospital data has provided insight into the severity and types of injuries sustained and their cost (Stutts et al. 1990; Veisten et al. 2007). However, Victoria Police has stated that as few as 1 in 30 cyclist collisions are reported (Harman 2007). Hence, research based on police-reported or hospital injury database crashes is unlikely to be representative of all cyclist crash types.

In the event of a cyclist fatality, the police reports are the primary source of post-event data, and are typically generated from the account of the driver involved and witnesses, often other drivers. This is problematic as there is likely to be recall bias and it is unlikely that drivers are able to provide an accurate account of the cyclist's pre-event actions or looking behaviour. Yet in an Australian report of cyclist deaths, cyclists were deemed to be responsible in over 60% of crashes and driver and/or cyclist failure to observe the other contributed to a third of crashes (Australian Transport Safety Bureau 2006). Further, in a recent report, cyclists' failure to 'look properly' was the main contributing factor in 31% of cyclist fatalities (Knowles et al. 2009). In order to gain new insights into pre-event behaviours, including cyclists' visual scanning behaviour, it is important to look beyond driver accounts and investigate the cyclists' perspective of events.

Arguably the best way to understand cycling crashes and the behaviours and circumstances that lead to these events is to observe cyclist–driver interactions in a naturalistic context. Naturalistic driving studies have provided detailed data on drivers in their 'natural environment'. In these studies, there is no attempt to control the road or driving environment; rather, road users are studied in situ with the use of video cameras. Naturalistic studies generate data on events that the participant may not consider noteworthy, yet may provide insights needed to improve safety without being reliant on the cyclist's memory or the relevant question to trigger a response.

The first comprehensive naturalistic driving study was the 100-Car Naturalistic Driving Study conducted by researchers at the Virginia Technology Transport Institute in the USA (Neale et al. 2002). The 100-car study was designed to investigate exposure and pre-crash behaviours. One hundred vehicles were instrumented with five cameras to record activity inside and outside the vehicle. Participants quickly disregarded the presence of the cameras and extreme driving behaviours were recorded including risk taking, aggressive driving and traffic violations (Dingus et al. 2006). Importantly, the research captured for the first time typically unreported minor events and insights into pre-collision behaviours. The naturalistic method has also been used to identify on-road behaviours of motorcyclists (Doerzaph 2008) and to evaluate the effectiveness of collision-avoidance systems including driver warning and vehicle control (McLaughlin et al. 2008).

Walker (2007) provided new insights into cyclist–driver interactions in relation to drivers overtaking behaviour. Walker, as the single participant cyclist, found that the overtaking distance drivers afforded cyclists was influenced by his appearance, 'sex' (he wore a wig and clothing to appear as a woman) and position on the road. The study used a combination of ultrasonic distance sensor, handlebar-mounted camera and laser pointer to measure the drivers' overtaking distance. However, the handlebar-mounted camera would have provided only a limited view of the cyclist's perspective and the interplay between the cyclist and drivers. It is likely that the use of a helmet-mounted camera would have provided insight into how the proximity of the passing vehicles influenced the cyclist's positioning on the road.

The use of head-mounted video cameras to record another perspective has had diverse applications such as televised sports coverage of motor sports and skiing (Brown et al. 2008), a surgeon's view of surgical procedures (Schneider et al. 2006), police activities in the UK (Associated Press 2007) and, increasingly, by the general public on video-sharing websites such as YouTube. Brown and colleagues (2008) used head-mounted cameras to explore the experiences of walkers and mountain bikers in rural Scotland. They found that the device freed the participant to concentrate on the activity, rather than the filming, and had untapped potential for investigating fast, dynamic activity. Spinney (2009:829) has also used video to explore a more nuanced understanding of the cycling experience and suggests that 'video has the potential to bring the researcher into the picture'.

The aim of this paper is to describe the application of a naturalistic driving method to investigate the behaviour of on-road commuter cyclists in metropolitan Melbourne. By adapting the approach used in the 100-car study (Neale et al. 2002), the method was used to investigate the entire commuter trip including all road types and traffic conditions experienced by participants.

METHODS

Four data sources were used in the study:

- video footage recorded using a helmet-mounted camera; this was the primary data source for information on cyclist–driver behaviour;
- a pre-study questionnaire;
- weekly email updates including progress reports of hours filmed, events experienced and problems experienced with the camera; and
- a semi-structured exit interview.

Details on the equipment and procedures relating to each data source are described below.

Helmet-mounted video camera and recording system

An Oregon Scientific ATC3K Action Camera was used to record all trips. The compact video camera was powered by two AA batteries and weighed approximately 240 grams. The footage was recorded at 640 × 480 VGA resolution at 30 frames per second. A standard 4GB memory card was provided with capacity to record up to 2 hours of footage per card. Participants were supplied with sufficient batteries and memory cards to record 12 hours of footage. A small LCD screen on the camera indicated how much memory had been used and participants changed the memory cards and batteries throughout the study. The data was downloaded by the researcher at the end of the study.

A pilot test was conducted to evaluate optimal camera-mounting positions and the helmet was the preferred location. Helmet mounting provided a view of the road environment that was closest to the cyclist's perspective and recorded head movements. Other mounting options evaluated were under-seat and handlebar mounts. Under-seat mounting provided the best view of the behaviour of vehicular traffic behind the cyclist and captured rear-end events. This is important as in Australia this collision type results in the highest proportion of cyclist fatalities (21%) (Australian Transport Safety Bureau 2006). However, the under-seat mount does not record forward travel and given the relative rarity of rear-end collisions, this rear-view option was discarded in favour of a forward-facing camera. Handlebar mounting was considered, as the camera could be secured and the footage recorded was stable. However, as noted in relation to the Walker (2007) study, a limitation of this mount is that this view does not capture cyclist's head movements or the broader environment, both important in the event of a collision or near-collision. Additionally, many commuter cyclists are likely to have equipment attached to their handlebars such as a trip computer, light and bell, and there may not be sufficient space to attach the video camera.

Extensive tests were conducted to determine the most effective means to attach the camera to the helmet. The manufacturer-provided accessories were used to attach the camera to the crown of the helmet. This position was unsuccessful as the camera was unstable and slid laterally resulting in unsteady, tilted footage. In addition, it was highly conspicuous and it was thought that this may influence the behaviour of drivers or other cyclists who observed the camera. The preferred mounting location was in a vent of the helmet, either on the crown or to the side, varying with the design of the participant's helmet. To fix the camera in this position, the camera was pressed into a bed of putty that lined the chosen vent and secured with an exterior grade reinforced tape positioned such that the back of the camera could be accessed to replace the memory cards and batteries. The putty minimised slippage and acted as a mild shock absorber. Nested in the helmet vent, the camera was less proud and therefore less visible and potentially less likely to influence the behaviour of other road users.

A camera was attached to each participant's helmet during the induction process. Participants rode short trial rides, which were downloaded to confirm the camera was in the correct position. Due to the strength of the mounting arrangement, participants could not easily remove the camera; however, the camera could be removed without damage to the helmet at the end of the study.

Other study components

Participants completed a pre-study questionnaire, weekly email updates and a semi-structured exit interview. The pre-study questionnaire was completed at induction and included 36 questions related to on-road cycling and driving behaviour, as well as standard demographic questions (Australian Bureau of Statistics 2007). All participants were contacted weekly by telephone or email, to monitor their progress. In these updates participants provided details of any collisions or near-collisions and the number of hours recorded. Semi-structured exit interviews were conducted and topics included how the presence of the camera may have affected behaviour and details of riding experiences.

Participants

Six participants completed the pilot study. Three females and three males were recruited using the snowball technique (Wasserman and Faust 1995). This population is not representative of the cycling population in Australia, which is 66% male (Department of Communications Information Technology and the Arts 2008). However, this study was intended to pilot the helmet camera and refine the method. A larger scale study is planned in which participants will be representative of the known commuter cyclist population. Inclusion criteria were adult commuter cyclists (over 18 years) who travelled on the road for the majority of their trip (70%) and commuted a minimum of 3 hours per week. All participants commuted to the Melbourne central business district. All non-electric bicycle types were accepted, with the exception of recumbent bicycles.

Data collected

The duration of footage required was calculated using the average distance ridden by commuter cyclists. In Victoria, the average distance ridden by commuter cyclists is 24.3 km return trip and over 50% of cyclists rode 3–5 days per week during the warmer months of October to March (Bicycle Victoria 2007). Participants were asked to ride their typical route and to ride as usual. No restrictions were placed on the time of day, nor were participants expected to ride an equal number of morning and afternoon rides.

The assumptions were that participants would ride the average distance for a minimum of 3 days per week at a speed of at least 20 km/h, the speed of a healthy, untrained adult (de Geus et al. 2007), resulting in 12 hours of recording over a 4-week period. The pilot study was conducted from January to April. It was also assumed that over the 12-hour period of recording participants would have time to become accustomed to the camera and 'forget' it was there, minimising behavioural bias.

As in other naturalistic studies, there is a systematic bias in participants' exposure, as the cyclists were regular commuter cyclists who rode at least 3 hours per week, more than triple the average cyclist's participation rate of 1 hour per week (Department of Communications Information Technology and the Arts 2008).

Data analysis

Analysis of the data was conducted in four stages: initial review of the footage, identification of collisions and near-collisions, calculation of incident rate, and classification of near-collision characteristics. The footage was reviewed using InterVideo WinDVD 5 viewing software. The data from the initial review was recorded using Excel spreadsheets, and the in-depth analysis of the near-collisions was conducted using an integrated video analysis software package called Snapper©[1]. The aggregated descriptive statistics were calculated using SPSS 15.0 for Windows.

The recorded image was inherently unstable due to a combination of head movement, jaunty body movements when pedalling and the roll of the bicycle over the road surface. In its original format, the footage caused severe reviewer nausea, which was minimised by processing the footage through a

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1 http://www.webbsoft.biz/prod_snapper.php

freeware image-stabilising software program called VirtualDub version 1.8.8 with an image stabiliser plug-in called Deshaker[2].

Initial review and data screening

An initial review was conducted to determine the amount of useable video footage, and low-light footage and time spend riding off road were excluded. Due to poor low-light sensitivity, footage recorded pre-dawn or post-dusk was mostly black with occasional vehicle headlight or tail light and details of the cyclist's trip could not be identified. Footage of off-road riding, namely off-road bicycle paths, parks and footpaths, was also excluded. Footage of riding in car parks, including underground car parks, was included in the data analysis.

Identification of collisions and near-collisions

Collisions and near-collisions were defined as per the 100-car study data dictionary (Dingus et al. 2006). The footage was reviewed to identify collisions, defined as an event in which the participants made contact with another road user in which kinetic energy was transferred or dissipated. Near-collisions or non-collision events in decreasing severity were also identified: near-crash, requiring rapid and evasive manoeuvre to avoid a crash; crash-relevant, requires evasive manoeuvre to avoid a crash, less severe than rapid movement; proximity conflict, extraordinarily close proximity of the subject vehicle with another vehicle; non-conflict, increases the level of risk associated with driving, but does not result in a crash or near-crash; and non-subject conflict, any incident captured on video that does not include the subject driver.

Collision and near-collision incidence rate calculation

The rates of collision and near-collisions were calculated using the number of collisions or near-collisions as the numerator and the number of on-road minutes observed (excluding low-light footage and time spent riding off road) as the denominator. This figure was multiplied by 60 to calculate the rate per hour.

Classifications of event characteristics

Collision and near-collision characteristics were further classified using modified variables from the 100-car study data dictionary and the VicRoads Definitions for Classification Accidents (DCA) codes. The 100-car study data dictionary classifies 44 collision or near-collision characteristics that comprehensively define elements of the event from a driver/vehicle focus. Some modification was needed to apply these variables to the cyclist footage. In total, 20 variables were adopted from the 100-car study without change. These include event severity, pre-incident behaviour, the road and traffic environment and the behaviour of the secondary vehicle involved. A further eight variables were modified, mainly changing the referent from driver to cyclist. Finally, 16 variables were excluded that mainly related to driver behaviour recorded by the internal cameras.

Two additional cycling-specific variables were developed and added to the data dictionary. First, head checks made by the cyclist and second, referred to cycling facility, the type and its absence or presence at the site of the event. The 100-car study variable that described the type of incident was replaced with the DCA codes. Accompanied by illustrative diagrams, the DCA codes were more specific and had more options than the 100-car study variable and will enable a direct comparison with the VicRoads CrashStats data.

RESULTS

Footage

In total, 68 hours and 55 minutes of footage was recorded by 6 participants. Approximately 32% of the time recorded was excluded due to low light or off-road riding. The descriptive statistics for the footage from the initial review is presented in *Table 1*.

In total, 22 hours and 38 minutes of footage recorded was excluded due to low light or riding off-road. Footage recorded by the female participants was more likely to be excluded due riding off road (23.3%) than riding in low light (8.9%). Footage recorded by male participants was more likely to be excluded due to riding during low light times (20.1%) than riding off-road (13.4%).

Rate of collision and near-collision events

No collisions were recorded. A total of 36 other, near-collision events were identified. The overall rate of near-collisions was 0.76 per hour. The rate for females was lower (0.38 per hour) than for males (1.13 per hour). The near-collision rates per hour are displayed in *Figure 1*.

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[2] http://www.guthspot.se/video/deshaker.htm

Table 1
Descriptive statistics of the participants' commute (am and pm)

	Time recorded (hours:mins)	Excluded time, low light (hours:mins)	Excluded time, off-road (hours:mins)	Total time for analysis (hours:mins)
Females (n = 3)	35:50	3:13	8:20	24:16
Males (n = 3)	33:05	6:38	4:27	22:00
Total	68:55	9:51	12:47	46:16

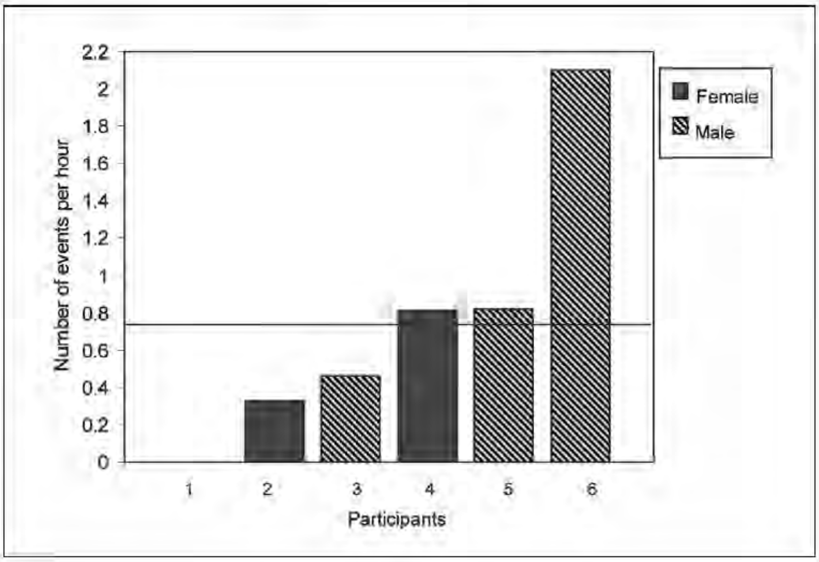

Figure 1
Individual participant rate of near-collision events per hour (median event rate)

Overall, the median event rate for all participants was 0.75. The median rate for the female participants was 0.38 per hour and included one participant who experienced no events. The median rate for the male participants was 1.13 and included the highest rate of 2.1 events per hour.

Event characteristics for each of the 36 events were coded to determine if all variables could be applied in a naturalistic cycling study. In total, 30 variables were coded for each event and provided extensive details on the behaviour of the cyclist and the driver pre-event and post-event as well as of the road environment. The results for 6 variables are presented in *Table 2*, to illustrate the types of information that can be derived from the video footage using the modified 100-car study variables.

Male participants experienced more than double (2.3) the number of near-collisions than female participants. A high percentage of incidents occurred while participants were travelling straight (females: 81.8%; males: 96%).

For males, the small proportion of events that did not occur during daylight hours (12%) occurred during the dawn period. A high proportion of events occurred with cars (light passenger vehicles) (77.7%) rather than trucks, buses or motorcycles. The use of bicycle lanes was observed in more of the events involving female riders (72.7%) than male riders (32%). Males were more likely to head check to the right prior to the event (60.0%) than females (36.3%).

DISCUSSION

The purpose of this study was to develop and trial a novel method for investigating and understanding experiences of on-road cyclists and how they interact with vehicles in the real-world environment. The process of recording the data was successful. All participants loaded and changed the batteries and memory cards in their cameras appropriately. The weekly updates by phone call proved to be too time consuming to manage and were replaced by email updates. This was more efficient for both the researcher and the participants, and provided an

Table 2
Summary of event characteristics (*n* = 36 events)

	Females(n = 3)	Males(n = 3)	Total(n = 6)
Number of events	11	25	36
Cyclist pre-incident – going straight	9	24	33
Lighting – daylight	11	22	33
Vehicle type – automobile	8	20	28
Bike lane present	8	8	16
Head checks (right)	4	15	17

opportunity for detailed descriptions of near-collision events that had been experienced.

The positioning of the camera on the cyclist's helmet captured video footage that was close to the cyclist's own viewpoint including head checks. The camera remained attached to the cyclist's helmet for the duration of the study; however, it did not always capture the cyclist's view of the road and sometimes recorded footage of the ground or the sky. This may have been due to a loose chin strap causing the helmet to slip during the ride. While all equipment and mounting was checked thoroughly at the time of fitment, it is possible that the helmet chin strap may have loosened during the study, resulting in poor alignment of the helmet and camera. For future research, more rigorous fitment checks may be required during the induction process to optimise the position and stability of the camera. Alternatively, a self-calibration exercise may increase the time the camera is in the correct position; for example, participants could conduct a mirror check to ensure a consistent position of the camera during the study.

Further, the use of a multiple camera system would provide additional detail of the cyclists' trips from different perspectives. For example, under-seat mounting would record the movements of the traffic behind the rider. This could have important implications for understanding risk factors for collisions in which a cyclist is hit from behind, the most common fatal crash type for cyclists in Australia (Australian Transport Safety Bureau 2006).

Participants frequently shook their head when riding, typically after a vehicle had not given sufficient space when overtaking or turning. The head shakes were clearly visible on the footage, and provided an unanticipated benefit of the helmet mounting. A review of events that elicit this response is likely to provide valuable insight into the situations where cyclists feel their space has been infringed upon.

All participants rode a portion of their commute off-road. Notwithstanding that all participants identified themselves as on-road commuters, each rider spent some time riding on off-road paths, on the footpath or through parks. Off-road spaces were most commonly used to access short cuts, often footpaths designed for pedestrian access, at the end of on-road bike lanes where cyclists are 'squeezed' off the road and onto the footpath and off-road bike paths. Female participants spent more time riding off-road than male participants.

Preliminary analysis showed a wide variation in frequency of events pre participant, from no events to more than two per hour. A larger sample of participants is required for more detailed analysis of behaviours including sex differences. The high proportion of observed events that occurred when participants were travelling straight and there was no deviation in their course may suggest that the near-collisions were due to driver behaviour. Further analysis of the footage will be conducted to determine whether driver or cyclist behaviour instigated the event. In the large-scale study, the analysis will include a detailed review of all variables, to attempt to determine the cause of the event as well as-

- whose actions led to the event (cyclist or driver);
- location details – cycling facility, traffic lanes and flow, surface condition;
- driver behaviour – vehicle manoeuvre, driver action, vehicle position; and
- cyclist head checks.

The low-light time recorded by the male participants was more than double that recorded by females. It is assumed that during the study period participants commuted at the time of day that they would usually ride. Most of the low-light riding time for females occurred at the end of their commute home, whereas the males rode in low light conditions on both morning and afternoon/evening commutes. The conclusions can be drawn from this finding are limited, due to the small number of participants in this pilot study; however, sex differences in riding in low light have been reported in previous studies. Research of Melbourne commuter cyclists by Garrard (2003) found differences between males and female riding times and suggested this might be due to different working hours, responsibilities at home or feelings of personal safety. Further investigation of night riding may have direct implications for night-time safety for cyclists, regarding cyclists' use of reflective clothing and adequate front and rear lighting.

The other stages of the study – the baseline questionnaire, weekly updates and exit interviews – were not analysed for this paper, as the methodologies for these approaches are well established (Silverman 2001). However, these data will be used in the analysis of the larger scale study to investigate the attitudes and beliefs of participants in relation to their on-road behaviours.

STRENGTHS AND LIMITATIONS

The main strength of this method was the continuous recording that allowed repeated, detailed analysis of the cyclists' entire trip. This is important for the identification of pre-collision and near-collision risk factors. The camera position provided the cyclist's point of view and important details about events that might not be reported by a cyclist post-event or be subject to recall biases.

The main limitation is the manual review and coding of the footage which is a resource-intensive process. However, manual review is currently the primary method of data reduction and is used to analyse footage from naturalistic driving studies (Neale et al. 2005, Dingus et al. 2006). Efficiencies were gained by establishing clear definitions of events and pre-screening to target the events of interest. In the future, it might be possible to automate some elements of the coding process and expedite the data reduction stage.

The camera's poor low-light sensitivity was another a limitation. This could be addressed by participants not filming during low-light times, although this would introduce a behavioural bias that would limit the conclusions that could be drawn about preferred commuter cyclist riding times. Alternatively, a camera with greater light sensitivity could be used and, as the video camera technology continues to improve with newer models, it is likely this limitation will be addressed.

CONCLUSION

This paper has described the novel application of naturalistic study methods to record and analyse the behaviour of commuter cyclists and drivers. The adaptation of the 100-car study definitions provided a framework to classify cyclist–driver near-collisions. The preliminary results have been able to establish a process for identifying near-collision rates not previously reported. This creates a starting point for further study of cyclist exposure to risk and to identify the components of collisions and near-collisions that need to be addressed to improve safety for on-road cyclists. A large-scale study using this method was planned to be conducted from October 2009 to March 2010 and it is anticipated that insights will be gained into the causal and contributing factors associated with in near-collisions and, potentially, collisions between cyclists and drivers.

REFERENCES

ASSOCIATED PRESS (2007). Head-mounted video cameras for British police, *The Wall Street Journal*, viewed 10 January 2010 at http://www.asiaone.com/News/AsiaOne+News/World/Story/A1Story20070714-18350.html.

AULTMAN-HALL, L and HALL, FL (1998). Research design insights from a survey of urban bicycle commuters, *Transportation Research Record* 1636, pp. 21-28.

AUSTRALIAN BUREAU OF STATISTICS (2007). *3101.0 Australian Demographic Statistics*, December 2007, viewed 21 April 2008 at http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0.

AUSTRALIAN TRANSPORT SAFETY BUREAU (2006). *Deaths of cyclists due to road crashes*, ATSB Road Safety Report, July 2006, Australian Transport Safety Bureau, Canberra.

BICYCLE VICTORIA (2007). *Report on National Ride to Work Day 2007, Registration by State/Territory*, Bicycle Victoria, Melbourne.

BROWN, KM, DILLEY, R and MARSHALL, K (2008). Using a head-mounted video camera to understand social worlds and experiences, *Sociological Research Online*, 13(6):1.

DAFF, M and BARTON, T (2005). Marking Melbourne's Arterial Roads to Assist Cyclists, ITE 2005 Annual Meeting and Exhibit, Institute of Transportation Engineers, Melbourne, viewed 10 July 2008 at http://209.85.173.104/search?q=cache:OxpPBB8gK4AJ:www.ite.org/Conference/SamplePaper.pdf+%22Advanced+stop+lines+for+cyclists%22andhl=enandct=clnkandcd=7andgl=usandclient=firefox-a.

DE GEUS, B, DE SMET, S, NIJS, J and MEEUSEN, R (2007). Determining the intensity and energy expenditure during commuter cycling, *British Journal of Sports Medicine*, 41, 8-12.

DEPARTMENT OF COMMUNICATIONS INFORMATION TECHNOLOGY AND THE ARTS (2008) *Participation in Exercise, Recreation and Sport Annual Report 2007*, Department of Communications Information Technology and the Arts, Canberra.

DINGUS, TA, KLAUER, SG, NEALE, VL, PETERSEN, A, LEE, SE, SUDWEEKS, J, PEREZ, MA, HANKEY, J, RAMSEY, D, GUPTA, S, BUCHER, C, DOERZAPH, ZR, JERMELAND, J and KNIPLING, RR (2006). *The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment*, Virginia Tech Transportation Institute.

DOERZAPH, Z (2008). Motorcycle rider naturalistic driving study, feasibility study of instrumentation to collect behavior data to identify on-road behaviors, *Naturalistic Driving Methods and Analyses Symposium*, Blacksburg, Virginia, Virginia Tech Transportation Institute.

GARRARD, J (2003). Healthy revolutions: promoting cycling among women, *Health Promotion Journal of Australia*, 14(3), 213-5.

HARKEY, DL and CARTER, DL (2006). Observational analysis of pedestrian, bicyclist, and motorist behaviors at roundabouts in the United States, *Transportation Research Record No. 1982* pp. 155-165.

HARMAN, B (2007). Bicycle safety and law enforcement, *Australasian Road Safety Research Policing and Education Conference*, Melbourne.

JOHNSON, M, CHARLTON, J and OXLEY, J (2008). Cyclists and red lights - a study of the behaviour of commuter cyclist in Melbourne, *Australasian Road Safety Research, Policing and Education Conference.* Adelaide, 10-12 November.

KNOWLES, J, ADAMS, S, CUERDEN, R, SAVILL, T, REID, S and TIGHT, M (2009). Collisions involving cyclists on Britain's roads: establishing the causes. TRL Report PPR 445, Transport Research Laboratory, Crowthorne.

McLAUGHLIN, SB, HANKEY, JM and DINGUS, TA (2008). A method for evaluating collision avoidance systems using naturalistic driving data, *Accident Analysis and Prevention* 40(1), 8-16.

NEALE, VL, DINGUS, TA, KLAUER, SG, SUDWEEKS, J and GOODMAN, M (2005). An overview of the 100-car naturalistic study and findings, *19th International Technical Conference on Enhanced Safety of Vehicles*, Washington.

NEALE, VL, KLAUER, SG, KNIPLING, RR, DINGUS, TA, HOLBROOK, GT and PETERSEN, A (2002). *The 100 Car Naturalistic Driving Study, Phase 1 - Experimental Design*, Virginia Tech Transportation Institute, Blacksburg, Virginia.

RIVARA, FP, THOMPSON, DC and THOMPSON, RS (1997). Epidemiology of bicycle injuries and risk factors for serious injury, *Injury Prevention* 3,110-4.

SCHNEIDER, E, BARTL, K, DERA, T, BÖNING, G, WAGNER, P and BRANDT, T (2006). Documentation and teaching of surgery with an eye movement driven head-mounted camera: See what the surgeon sees and does, *in* Westwood, JD et al. (Eds.) *Medicine Meets Virtual Reality 14- Accelerating Change in Healthcare: Next Medical Toolkit*, IOS Press, Amsterdam.

SILVERMAN, D (2001). *Interpreting Qualitative Data*, Sage Publications, London.

SPINNEY, J (2009). Cycling the city: Movement, meaning and method, *Geography Compass*, 3/2, 817-835.

STUTTS, JC, WILLIAMSON, JE, WHITLEY, T and SHELDON, FC (1990). Bicycle accidents and injuries: a pilot study comparing hospital- and police-reported data. *Accident Analysis and Prevention*, 22(1), 67-78.

VEISTEN, K, SÆLENSMINDE, K, ALVÆR, K, BJØRNSKAU, T, ELVIK, R, SCHISTAD, T and YTTERSTAD, B (2007). Total costs of bicycle injuries in Norway: Correcting injury figures and indicating data needs, *Accident Analysis and Prevention*, 39(6), 1162-1169.

WALKER, I (2007). Drivers overtaking bicyclists: Objective data on the effects of riding position, helmet use, vehicle type and apparent gender, *Accident Analysis and Prevention*, 39(2), 417-25.

WASSERMAN, S and FAUST, K (1995). *Social network analysis: Methods and applications*, Cambridge University Press.

WATSON, L and CAMERON, M (2006). *Bicycle and Motor Vehicle Crash Characteristics*, Research Report 251, Monash University Accident Research Centre, Melbourne.

Chapter 8 Publication 4

Naturalistic cycling study results

The naturalistic cycling study was successfully piloted as discussed in Chapter 7. During the pilot study, participants reported that most cyclists did not appear to notice the camera or if they did notice it, they thought it was a light. No participants were approached by drivers and it may be assumed that drivers were not aware that they were being filmed. All six of the pilot study participants reported that when wearing the camera they rode as usual and did not change their behaviour during the filming.

One unexpected consequence of the camera was reported by one of the female participants who reported that having the camera gave her a feeling of protection. While she was not aware of this during the study, after the study she reflected that having the camera gave her confidence in traffic. Being able to record a driver's behaviour and their licence plate details just by looking at them, particularly drivers' whose behaviour she felt was threatening, gave her a sense of protection. When she returned the camera, she said she felt her protection had been removed and that if there was an event involving a driver in subsequent trips that she would not have any proof of the behaviour.

The pilot study was successful in developing the naturalistic cycling study method for use in analysing cyclist-driver collision and near-collision events. However, with only six participants, limited conclusions could be drawn from the footage. Further the pilot study participants were both males (n=3) and females (n=3) and it was considered important to investigate a sample group that was more representative of the gender proportions that had been observed on the roads during the observation study, that is more males, closer to the 70 per cent observed.

In the pilot study, no collision events were observed and a total of 36 events were identified. From the preliminary analysis in the pilot study, it was considered important to further investigate the role of driver behaviour in the near-collision as pre-event most of the cyclists were travelling straight and without deviation. As the focus of Publication 3 was on developing the methodology, an in-depth analysis was not conducted of the results from the pilot study. Consequently, a more detailed review of the contributory factors, especially the pre-event factors, was conducted in the fourth publication, presented in this chapter. The naturalistic cycling study addressed three research questions in this doctoral research:

- *What are the behaviours and characteristics of road users that place cyclists at risk?*
- *What is the role of cycling infrastructure/facilities in cyclist-driver interaction and behaviour?*
- *What contributing factors can be identified in cyclist-driver collision and near collision events?*

Publication 4

The full naturalistic cycling study was conducted. The study was conducted from October to December 2009. As discussed in Chapter 4, this is during the daylight savings period in Victoria and typically is a period of warmer weather.

In this period, 13 participants each recorded 12 hours of their commuter cycling trips over a one-month period. Collectively, the 13 participants recorded over 127 hours of footage while cycling on-road. The footage was repeatedly reviewed and all events, using the 100-car study definition of events, were identified and analysed.

In total, 54 events were identified. The events ranged from a collision (2), an actual collision that involved kinetic energy transference, to a near-collision (6) that required rapid, evasive manoeuvring by the cyclist and/or driver to avoid a collision, to an incident (46) which required some evasive action to avoid a collision but was less severe than a near-collision. Each of these events was carefully, manually analysed, often frame-by-frame. The modified 100-car study data dictionary was used to code the pre-event, event and post-event factors including the behaviours of the cyclist participant and the driver of the vehicle involved as well as details of the road environment.

Key findings were related to driver behaviours. The majority (72.2%) of the events occurred when the driver turned left across the path of cyclists travelling straight across the intersection. This type of event included when the driver turned left, merged or changed lanes. During many of these manoeuvres, drivers did not indicate (signal) their intended change of direction. Recommendations were made and specifically address cyclist and driver behaviour and changes to improve road design and operation.

The study provides important new insights into the pre-event factors in cyclist-driver collision and near-collision events. A manuscript that included the analysis of the footage for 13 commuter cyclists was submitted to the 54th annual conference of the Association for the Advancement of Automotive Medicine (AAAM) in Las Vegas, Nevada, 17-20 October 2010. The paper was peer-reviewed and accepted for presentation and was published in October 2010 in the conference proceedings, *Annals of Advances in Automotive Medicine*, Volume 54 and is indexed on the US National Library of Medicine service, PubMed. The final published version of this paper is presented in Section 8.1.

Notation: In the publication overleaf, the road rule related to driver indication was misinterpreted. In the paper, it states that the road rule regarding indicating requires drivers to indicate for five seconds prior to turning left or right. This is an error.

The law actually states that signalling for five seconds is only required when: ‘the driver is about to change direction by moving from a stationary position at the side of the road or in a median strip parking area, the driver must give a change of direction signal for at least five seconds before the driver changes direction (Rule 46(3)) (Australian Transport Council, 1999).

Correction: The aggregated percentage of actions that involved the vehicle in the adjacent lane turning or merging left across the path of the cyclist was reported as 72.2% (Publication 4, p154). This should have been 73.9%.

Further, reference to signalling at other times refers to drivers giving ‘sufficient warning’ however sufficient warning is not quantified. Driver signalling behaviour and its impact on cyclist safety is discussed further in Chapter 10.

Monash University

Declaration for Thesis Chapter 8

8.1 Naturalistic cycling study

Declaration by candidate

In the case of the publication presented in Chapter 8, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
▪ Concept and design – initial concept, development of study design ▪ Acquisition of data – data collection, data management, supervision of data quality, operation of technical equipment ▪ Analysis and interpretation – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures/illustrations, revision/editing for intellectual content	80%

The following co-authors contributed to the work.

Name	Nature of contribution
Dr Judith Charlton Dr Jennie Oxley	▪ Concept and design – initial concept, development of study design, statistical concepts ▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content
Dr Stuart Newstead	▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Publication preparation – paper outline, preparation of figures, revision/editing for intellectual content

[redacted]

Candidate's signature

20 May 2011

Date

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location: Monash University Accident Research Centre, Clayton campus

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Dr [redacted]ith Charlton

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Dr Stuart Newstead

16/5/2011

Date

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NATURALISTIC CYCLING STUDY: IDENTIFYING RISK FACTORS FOR ON-ROAD COMMUTER CYCLISTS

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ABSTRACT – The study aim was to identify risk factors for collisions/near-collisions involving on-road commuter cyclists and drivers. A naturalistic cycling study was conducted in Melbourne, Australia, with cyclists wearing helmet-mounted video cameras. Video recordings captured cyclists' perspective of the road and traffic behaviours including head checks, reactions and manoeuvres. The 100-car naturalistic driving study analysis technique was adapted for data analysis and events were classified by severity: collision, near-collision and incident. Participants were adult cyclists and each filmed 12 hours of commuter cycling trips over a 4-week period. In total, 127 hours and 38 minutes were analysed for 13 participants, 54 events were identified: 2 collisions, 6 near-collisions and 46 incidents. Prior to events, 88.9% of cyclists travelled in a safe/legal manner. Sideswipe was the most frequent event type (40.7%). Most events occurred at an intersection/intersection-related location (70.3%). The vehicle driver was judged at fault in the majority of events (87.0%) and no post-event driver reaction was observed (83.3%). Cross tabulations revealed significant associations between event severity and: cyclist reaction, cyclist post-event manoeuvre, pre-event driver behaviour, other vehicle involved, driver reaction, visual obstruction, cyclist head check (left), event type and vehicle location ($p<0.05$). Frequent head checks suggest cyclists had high situational awareness and their reactive behaviour to driver actions led to successful avoidance of collisions/near-collisions. Strategies to improve driver awareness of on-road cyclists and to indicate early before turning/changing lanes when sharing the roadway with cyclists are discussed. Findings will contribute to the development of effective countermeasures to reduce cyclist trauma.

INTRODUCTION

Cycling is the fourth most popular physical activity in Australia, behind walking, aerobic/fitness and swimming, and the number of people riding bicycles is increasing, up 11% from 2001 to 2007 (Department of Communications Information Technology and the Arts, 2008). All levels of Australian government have road safety strategies that incorporate cycling and some have cycling specific strategies (Austroads, 2005, VicRoads, 2008c, City of Melbourne, 2007). Cycling facilities that have benefited cyclist safety in the United Kingdom, Europe and the United States (McClintock and Cleary, 1996, Pucher et al., 2010) have been implemented in Australian jurisdictions (eg bicycle lanes and bicycle storage boxes/advanced stop lines) to create a delineated space for cyclists on the road.

Notwithstanding the rise in participation, nationally the number of cyclist fatalities has remained relatively constant with an average of 37 cyclist deaths per year from 1999 to 2008 (Department of Infrastructure, 2009). However, there has been a dramatic increase in the number of crashes resulting in cyclist serious injuries (Berry and Harrison, 2008, Sikic et al., 2009). As the number of cyclists on the road continues to increase, the potential for cyclist-driver collisions is a growing concern, particularly as these collisions result in the most severe injury outcomes and poorest survival rate for cyclists (Bostrom and Nilsson, 2001).

An Australian review of police and coronial reports for 222 cyclist fatalities found that in over 60% of collisions a major contributing factor was that cyclists and drivers did not see each other (Australian Transport Safety Bureau, 2006). Numerous studies have sought to investigate the looking behaviour of drivers: driver hazard perception (Benda and Hoyos, 1983), at intersections and the role of speed reducing countermeasures (Summala et al., 1996, Summala and Rasanen, 2000) and detecting approaching motorcyclists (Clarke et al., 2007). Investigations of visual scanning strategies have found many drivers looked-but-failed-to-see cyclists (Herslund and Jørgensen, 2003), and that drivers look to cyclists' faces to assess intended behaviour rather than their hand/arm (Walker, 2005, Walker and Brosnan, 2007). However, less attention has been given to understanding the *in situ* looking behaviour and situational awareness of cyclists pre-event in relation to collisions or near-collisions.

In the United Kingdom, helmet mounted cameras have been used in mobility research to investigate the experiences of mountain bike riders (Brown et al., 2008) and riding styles in London (Brown and Spinney, 2010). However, these studies focused on the development and critique of video ethnography as a method that could provide researchers with a virtual ride-along experience that had not been achieved via other methods. It is believed that to date, this method has not been used to investigate how cyclists and drivers interact on the road and the risk factors associated with collisions and near-collisions.

In addition, there are limitations in using post-event data to understand pre-crash factors and it is difficult to determine the looking behaviour of a cyclist prior to a fatality collision (Räsänen and Summala, 1998). The data is typically generated by statements from the driver involved or witness accounts, both subject to reporting biases and errors; or from crash scene investigations which are not able to provide details on all salient cyclist-related pre-event actions. In fatal crashes, clearly the deceased cyclist is unable to contribute, however, additional cyclist-related data may be generated if the cyclist was riding in a group. To better understand the role of cyclist looking behaviour and the contributing factors of other situational and behavioural factors it is important to understand what cyclists see when riding and their reactions to the traffic environment.

Looking behaviour of cyclists

Cyclist visual scanning research has found that head checks are an important indicator of intended behaviour. Räsänen and colleagues conducted video observations in a study of yield behaviour at intersections following a change in Finnish legislation regarding vehicle priority. An analysis of the head movements of 2,112 cyclists found an association between more frequent head movements with greater caution (Räsänen et al., 1999).

In a series of studies, Plumert and colleagues investigated the behaviour of cyclists using a range of traffic scenarios in a bicycle simulator (Plumert et al., 2004, Plumert and Kearney, 2007, Plumert et al., 2007). The research focused on the cognitive and perceptual skills of children and behaviour at intersections, particularly gap selection differences between children and adults. The focus on child riders provided useful insights into children's cycling behaviour and decision making processes; however these studies included little detail of adult cyclists' looking patterns. Moreover, many questions remain about adult cyclists, their behaviour when interacting with drivers, how drivers interact with cyclists and the on-road space afforded to riders.

Systems approach

Beyond cyclist-driver behaviours, it is important to consider how the road network and the environment may potentially contribute to crash and injury risk. To focus solely on the behaviour of cyclists and drivers assumes that the road network system is perfect and it is only due to errors by the road users a crash occurs (Larsson et al., 2010). The road user approach lacks an understanding of the importance of interactions between all components of the traffic system and emergent issues.

The actions of cyclists and drivers on the road are facilitated and shaped by the design of the road (Elvebakk and Steiro, 2009). There has been little attention given to the safety implications of the on-road cycling facilities and how cyclists and drivers negotiate the available space on the road. This is of particular importance in Australia, where to date a range of on-road cyclist facilities, primarily painted lines, have been implemented. However, there have not been broad public communication/education campaigns for drivers that explain the facilities or to help drivers understand how to interact with the increasing number of cyclists on the roads.

The aim of this study was to investigate the pre-event behaviours and environment to identify risk factors for collisions and near-collisions involving on-road cyclists and drivers. Given the increasing number of cyclists in Australia, and the lack of research focus on the safety implications of the pre-event risk factors, it is anticipated that the findings will contribute substantially to the knowledge of factors that affect cyclists' safety and highlight recommendations that may reduce cyclist trauma.

METHODS

Research design

This was a naturalistic study of on-road commuter cyclists. A video camera was attached to participants' bicycle helmet, each participant recorded 12 hours of their commuter cycling trip over a 4-week period. The study was conducted during warmer months from October to December 2009, commencing with the start of daylight savings (summer time).

Helmet mounted video camera

The compact video cameras used (Oregon Scientific ATC3K Action Camera) were powered by two AA batteries and weighed approximately 240gm with the memory card and batteries installed. Footage was recorded at 640 x 480 VGA resolution at 30 frames per second. Participants were provided with 6 memory cards (4GB) and sufficient batteries. A display screen indicated recording time remaining on the memory card and participants changed the cards and batteries as required. The data was downloaded by the researcher at the end of the study.

Extensive pilot testing was conducted to determine the most suitable camera position including on the handlebars and under the seat. The handlebar mount was discounted as it did not capture cyclists' head movements or the broader environment which are important in the event of a collision or near-collision (Walker, 2007). Further, there were potential space limitations on the handlebars due to other equipment that may already be attached eg trip computer or lights. The under-seat mount clearly recorded the vehicular traffic behind the rider and would capture rear-end events. This perspective was of interest as rear-end collisions result in the highest proportion of cyclist fatalities in Australia (21%) (Australian Transport Safety Bureau, 2006). However, despite risk of fatal outcome, rear-end collisions are rare and this mounting was discarded in preference of a forward-facing camera position.

In the study induction, the camera was attached to the helmet and each participant rode a short test ride. Test footage was reviewed and the camera position was adjusted if necessary. The camera was secured with adhesive putty and an exterior grade reinforced tape and remained attached for the study duration. Camera position varied depending on bicycle type, helmet design and participant's position on the bicycle.

Participant recruitment

The participant inclusion criteria were: over 18 years, regularly cycle commuted to and from work, travelled the majority of trip (70%) on-road and able to film 12 hours of footage over a 4-week period. All non-electric bicycle types were accepted, excluding recumbent bicycles.

A quota sample of participants was sought to include footage from a range of approach routes into the Melbourne central business district (CBD). The installation of cycling facilities and traffic calming measures is not uniform across the city. Initially, participants were recruited using a snowball technique however this process failed to yield participants who used the most frequently used on-road commuter route into the CBD (along St Kilda Road). Targeted recruitment via an article in the local newspaper was used to recruit commuters in the area.

Data collected

Footage

The recording time of 12 hours was calculated using the average distance ridden by commuter cyclists, which in Victoria is 24.3km (return trip). During the warmer months of October to March, over 50% of cyclists rode 3-5 days per week (Bicycle Victoria, 2007). The assumptions were that participants would ride the average distance, a minimum of 3 times per week and ride at least at the average speed of a healthy, untrained adult (20km/h)(de Geus et al., 2007).

It was also assumed that 12 hours of trips would provide a range of experiences representative of typical trips and also give participants the opportunity to 'forget' their behaviour was being filmed. Drivers in the 100-car study were found to be cautious at the beginning of the study, however, this effect wore off after the first hour (Dingus et al., 2006).

Other data

In addition, participants completed a survey about their driving/cycling experiences, provided weekly updates and completed an exit interview about their study experience, cycling safety and general topics including helmets, headphones and registration. These data are not considered in this paper.

Data analysis

Data analysis was conducted in four stages: an initial footage review; identification of events, classification of event characteristics and; statistical analysis. Excluded was footage recorded when participants rode off-road including bike paths and footpaths and; footage recorded during low light hours as the camera had poor light sensitivity.

The footage was reviewed using InterVideo WinDVD 5 viewing software. Aggregated descriptive statistics and cross-tabulations were calculated using PASW Statistics 18.

Definitions

The definitions used were adapted from the first comprehensive naturalistic driving study (Neale et al., 2002). The study was the 100-car study conducted by researchers at the Virginia Technology Transport

Institute in the United States of America and used using five cameras in each of the 100 vehicles. The footage recorded for the first time typically unreported minor events and insights into pre-collision behaviours.

The 100-car study included five levels of event severity, however the level of detail required to use these definitions was not recorded by a single camera. Three event severities were identified: collision, near-collision and incident. A *collision* involved contact between the cyclist and another road user with kinetic energy transference. A *near-collision* required rapid, evasive manoeuvring from the cyclist and/or the driver to avoid a collision, eg sudden braking or swerving. An *incident* required some collision avoidance, but was less sudden than the near-collision event and included close vehicle proximity which results when drivers did not allow sufficient space when overtaking cyclists.

Event characteristics were classified using modified variables from the 100-car study data dictionary and incident types were classified using codes from the VicRoads Definitions for Classifying Accidents (DCA)(VicRoads, 2008a). The 100-car study data dictionary classified 44 incident characteristics which comprehensively define elements of the event from a driver/vehicle perspective. Some modification was needed to adapt the variables to the cyclist footage.

In total, 20 variables were adopted from the 100-car study without change, including pre-incident behaviour, the road and traffic environment and the behaviour of the secondary vehicle involved. Included was the variable *fault*, defined as cyclist/driver who committed an error and was only coded if there was observable evidence.

A further eight variables were modified, mainly changing the referent from driver to cyclist and adapting the references to the Australian driving context (left lane drive). The *pre-incident manoeuvre judgement* variable included *safe and legal*. This was defined in the 100-car study based on vehicle kinematics. The definition was modified to describe the positioning of the participant, both on the road and in relation to vehicular traffic. For example, riding straight, in an on-road bicycle lane would be coded as *safe and legal*. In addition, the variable related to direction and speed of travel (*going straight, constant speed*) was modified to include direction only (*going straight*) as cyclists' speed was not recorded.

In total, 16 variables were excluded, mainly related to driver behaviour recorded by the internal cameras used in the 100-car study. Additional cycling specific variables were developed and included cyclist head checks, cycling facility presence/type at the event site and use of vehicle indicators prior to lane changes.

In observational studies there is potential for coding bias, particularly when only one researcher codes all the data. To address this, an independent researcher recoded two variables (*event severity* and *event nature*) for 6 of the 54 events (11.1%). The results were analysed using the Kappa statistic. The inter-rater reliability were *event severity*, Kappa = 0.667 and *event nature* Kappa = 0.769. Both measurements can be interpreted as being of substantial agreement (Landis and Koch, 1977).

RESULTS

Footage

The total time recorded by all participants was 138 hours 51 minutes. In total, 11 hours and 13 minutes of footage was excluded due to riding off-road or low light. After exclusions, the total video footage available for analysis was 127 hours 38 minutes. Summary statistics for the video recordings are presented in Table 1.

Table 1 - Descriptive statistics of the recorded footage (AM & PM)

	Females (n=2)	Males (n=11)	Total
Time recorded	21:18	117:33	138:51
Excluded time			
- Low light	0:25	1:39	2:04
- Off road	2:25	6:44	9:09
Total time analysed	18:28	109:10	127:38

Events

In total, 54 events were identified: 2 collisions, 6 near-collisions and 46 incidents. The descriptive statistics for selected variables are cross tabulated with event severity and presented in Table 2.

Most cyclists were observed to be riding in a safe and legal manner pre-event (87.0%). Prior to the events, cyclists were observed making right head checks (57.3%) but fewer left head checks (37.1%). With the exception of the 2 collisions, all cyclists maintained control of their bicycle and most avoided a collision by braking (75.9%).

Table 2 – Summary data for key variables for each event severity type (n=54 events)

		Event severity				
		Collision	Near collision	Incident	Total	(category %)
Number of events		2	6	46	54	(100%)
Time	AM	2	5	23	30	(55.6%)
	PM	-	1	23	24	(44.4%)
Traffic control	no traffic control	2	4	41	47	(87.0%)
	traffic signal	-	2	3	5	(9.2%)
Relation to junction	non-junction	1	2	12	15	(27.7%)
	intersection/ intersection-related	1	4	33	38	(70.3%)
Bike lane	yes	1	2	21	24	(44.4%)
	no	1	4	25	30	(55.6%)
DCA code	110 Cross traffic	2	-	-	2	(3.7%)
	116 Merging from left	-	-	9	9	(16.6%)
	135 Sideswipe	-	3	19	22	(40.7%)
	137 Left turn across	-	1	8	9	(16.6%)
	163 Vehicle door	-	-	2	2	(3.7%)
Fault	driver	1	4	42	47	(87.0%)
	cyclist	1	1	3	5	(9.2%)
	unknown	-	1	1	2	(3.7%)
Cyclist pre-event behaviour	safe and legal	1	4	42	47	(87.0%)
	unsafe and illegal	-	-	2	2	(3.7%)
	safe but illegal	-	-	1	1	(1.8%)
	unsafe and legal	1	2	1	4	(7.4%)
Cyclist head check – left	no	1	3	30	34	(62.9%)
	1-5 times	1	2	2	5	(9.2%)
	5+ times	-	1	14	15	(27.7%)
Cyclist head check – right	no	2	3	18	23	(42.5%)
	1-5 times	-	1	12	13	(24.0%)
	5+ times	-	2	16	18	(33.3%)
Cyclist reaction	steered to the left	-	1	3	4	(7.4%)
	braked	1	2	13	16	(29.6%)
	slowed (shook head)	-	1	24	25	(46.2%)
	no reaction	-	-	6	6	(11.1%)
Cyclist post-event	maintained control	-	6	46	52	(96.2%)
	did not maintain control	2	-	-	2	(3.7%)
Vehicle type	car	1	2	30	33	(61.1%)
	4WD/SUV	1	1	5	7	(12.9%)
	large/commercial vehicle	-	3	8	11	(20.3%)
	motorcycle	-	-	2	2	(3.7%)
Driver pre-event behaviour	illegal passing	-	-	3	3	(5.5%)
	did not see cyclist	2	5	10	17	(31.4%)
	turned/merged too close in front of cyclist	-	-	30	30	(55.5%)
Vehicle indicated	yes	-	2	22	24	(44.4%)
	no	-	4	14	18	(33.3%)
	N/A, unknown	2	-	10	12	(22.2%)
Driver reaction	no reaction	-	4	41	45	(83.3%)
	braked	2	2	5	9	(16.6%)

The most frequent event type observed was sideswipes (40.7%). When grouped together with other actions that involved the vehicle in the adjacent lane turning or merging left across the path of the cyclist, this type of action resulted in 72.2% of all events observed (example see Figure 1). The two collisions observed involved cross traffic.

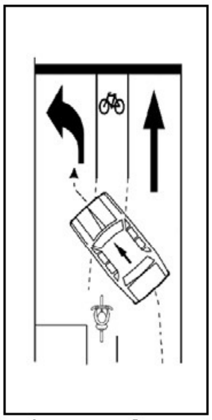

Figure 1 Left turn across cyclist path

Drivers were determined to be at fault in the majority of events (87.0%). In these driver-at-fault events, the most frequent event type was driver left manoeuvres including turning left and turning left across the path of the cyclist (55.5%). This was the most frequent pre-event driver behaviour across all vehicle types, with the exception of 4WD drivers who were more likely to not see the cyclist (85.7%). Post-event there was no identifiable reaction from the driver, such as braking or slowing (83.3%).

The vehicle indicator status was known for most events (77.8%), unknown for 11.1% and not applicable for 11.1% of the events. When the vehicle's indicator could be observed, 57% of drivers did indicate (or signal) before they changed course. However, of the drivers who did indicate, half (50.0%) indicated for only 1-3 seconds before changing course.

A similar number of events occurred during the morning (55.6%) and afternoon (44.4%) trips. The majority of events occurred at intersections or at intersection-related sites (70.3%); however the majority of these sites did not have any form of traffic control (including traffic lights or signage) (87.5%). There was no designated bike lane at over half the sites where an event occurred (55.5%).

Each variable was cross tabulated with event severity and Fisher's Exact Test, a test to determine the significance of associations between categorical data, was used. Significant associations ($p<0.05$) were found between event severity and pre-event factors: pre-event driver behaviour (turned/merged too close in front of cyclist), cyclist reaction (braked), cyclist head check (left); event type (sideswipe); and post-event factors, cyclist post-event manoeuvre (maintained control) and driver reaction (no reaction).

DISCUSSION

All identified collisions, near-collisions and incidents were analysed in-depth to identify the risk factors for cyclists. Overall, on-road commuter cyclists rode in a safe and legal manner and used cycling facilities when available. In addition, cyclists rode in a manner that was anticipatory (avoiding potential collisions) and defensive or reactive to the surrounding vehicular traffic as drivers did not appear to see them.

Cyclists made frequent head checks throughout their commuter trips, which suggests cyclists have high situational awareness. However, in general, cyclists were less likely to look to the left. Australia has left lane direction travel, and the reduced checking to the left – the direction which should give way to the cyclist – has also been observed in driving studies where drivers are less likely to look in the direction of the 'lesser threat'(Summala et al., 1996).

Drivers were deemed at fault in the majority of events. In a small number of events, the cyclist did not react before the event which suggests they did not have time to react or did not see the vehicle. These findings suggest that events are more likely to be attributed to a lack of awareness by drivers rather than cyclist inattention. This points to a need to improve driver awareness of other road users. However, there may also be a role for educating or training cyclists to ride more defensively around cars and be particularly vigilant of drivers turning left across their path at intersections, particularly vehicles with poor visibility traits such as large vehicles and 4WDs. Educational information aimed at cyclists and large goods vehicle drivers has been developed in the United Kingdom, following cyclist fatalities that have resulted from large vehicle-cyclist collisions (London Cycling Campaign, 2006, Transport for London, 2010).

The majority of events involved drivers' lane change behaviour (sideswipe/left turn-related). Drivers' lane change behaviour appeared to be motivated by a gap in the adjacent vehicle lane. At times, this resulted in a sudden lane change and often drivers did not indicate (signal), despite the Australian Road Rule that all drivers must indicate for at least 5 seconds prior to turning left or right (Australian Transport Council, 1999). Drivers did not appear to be aware of the cyclist travelling alongside or behind them. While this behaviour did not appear to impact surrounding vehicular traffic, sudden vehicle lane change had a dramatic impact on the cyclist. Successful collision avoidance was reliant on the cyclist's bike handling skills and reaction time.

Cyclists' capacity to affect a response manoeuvre is likely to be influenced by their travel speed. Participants were not fitted with a speedometer or global positioning system (GPS), so travel speed could not be validated. However, cyclists frequently checked their trip computer when riding and the digital readout was occasionally recorded on the video and showed speeds in excess of 40km/h. It is likely that such speeds contribute to cyclists' ability to successfully manoeuvre around a vehicle that makes a sudden change in course. Further research is needed to determine the importance of cyclist travel speeds and available time for collision avoidance manoeuvres, particularly among male cyclists whose observed speeds were higher than for female cyclists.

Given the high proportion of events that were sideswipe/left turn events, adequate overtaking distances are required to ensure that cyclists are afforded a safe clearance space on the roads (Walker, 2007). The need for a one metre clearance zone when overtaking cyclists is promoted by the road authority (VicRoads, 2008b) and included in the learner drivers' handbook (VicRoads, 2007) An education campaign with the message that *a metre matters* has brought attention to the need for greater clearance (Amy Gillett Foundation, 2009). However, observed drivers did not provide sufficient clearance when overtaking cyclists. It is likely that there is also a role for enforcement to shift driver behaviour when overtaking cyclists.

Moreover, it would be ideal if drivers were aware of cyclists and looked for them at all times. However, a practical recommendation with immediate benefits for cyclists would be to increase driver awareness of their requirement to indicate for at least 5 seconds before changing course. This would give cyclists around them time to adjust their line of travel. This could be emphasised in new driver training programs, accompanied by an education campaign and penalties enforced in serious collisions when driver failure to indicate was found to be a contributing factor.

Cyclists also need to take responsibility for their safety, by riding safely and legally and maximising their conspicuity. Conspicuity relates to the visibility of the cyclist by wearing light, reflective clothing and use of front and rear bike lights of sufficient luminance. Also, cyclists need to ensure their position on the road maximises their conspicuity and avoid riding in drivers' blind spots.

Lastly, it is important to consider the role of the road infrastructure and cycling facilities in cyclist safety. A bicycle lane was present in less than half of the observed events and across all event severities. The cycling lanes observed were disjointed and often ended abruptly, frequently where the road narrowed, without a viable option for the cyclist who then either continued in the lane along the kerbside, directly competing with vehicular traffic for space, or rode (illegally) on the footpath. Greater consistency in cycling facility design is needed. A review of existing cycling facilities is also required to improve continuity and provide intuitive end-point options to ensure the road space afforded to cyclists is identifiable. A comprehensive education campaign to ensure cycling facilities are understood by all road users is needed.

Strengths and limitations

The strength of this study was the provision of extensive data on the details of cyclist-driver events. As near-collisions and incidents are not officially reported, the data generated in this study has not been available via any other data source. Due to the positioning of the video camera, this study has provided important insights into the interactions between cyclists and drivers on the road.

The main limitation was a bias caused by the video camera technology. It was identified in the pilot study that the video camera had poor low light sensitivity. Footage recorded pre-dawn or post-dusk was primarily black and no details of the cyclists' trip could be identified (Johnson et al., 2010). Therefore, participants were encouraged to not record their trip during this time. Cyclists did ride during low light times but did not record these trips and therefore there was an overrepresentation of riding during daylight hours in the recorded footage. This limitation is likely to be addressed by advanced in compact video technology.

CONCLUSION

This study has generated a valuable new, in-depth dataset for naturalistic cycling. This practical method provided the cyclists' perspective and allowed analysis of factors mostly highly associated with events and importantly, generated detailed data on the pre-event behaviours of the cyclists and the drivers. Future research using this methodology may include different types of cyclists to determine if the contributing factors identified among commuter traffic are similar in other cyclist types.

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REFERENCES

Amy Gillett Foundation (2009) A metre matters. http://www.amygillett.org.au/a-metre-matters, Viewed on 26 March 2010.

Australian Transport Council (1999) Australian Road Rules.

Australian Transport Safety Bureau (2006) Deaths of cyclists due to road crashes. Australian Government.

Austroads (2005) The Australian National Cycling Strategy 2005-2010. Sydney.

Benda, HV & Hoyos, CG (1983) Estimating hazards in traffic situations. *Accident Analysis & Prevention,* 15, 1-9.

Berry, JG & Harrison, JE (2008) Serious injury due to land transport accidents, Australia, 2005-2006.

Bicycle Victoria (2007) Report on National Ride to Work Day 2007, Registration by State/Territory. Melbourne.

Bostrom, L & Nilsson, B (2001) A Review of Serious Injuries and Deaths from Bicycle Accidents in Sweden from 1987 to 1994. *Journal of Trauma-Injury Infection & Critical Care,* 50, 900-907.

Brown, K & Spinney, J (2010) Catching a Glimpse: The Value of Video in Evoking, Understanding and Representing the Practice of Cycling. IN Fincham, B., McGuinness, M. & Murray, L. (Eds.) *Mobile Methodologies.* Hampshire, Palgrave Macmillan.

Brown, KM, Dilley, R & Marshall, K (2008) Using a Head-Mounted Video Camera to Undersand Social Worlds and Experiences. *Sociological Research Online,* 13 (6) 1.

City of Melbourne (2007) The City of Melbourne Bicycle Plan 2007-2011. Melbourne, City of Melbourne.

Clarke, DD, Ward, P, Bartle, C & Truman, W (2007) The role of motorcyclist and other driver behaviour in two types of serious accident in the UK. *Accident Analysis & Prevention,* 39, 974-981.

de Geus, B, De Smet, S, Nijs, J & Meeusen, R (2007) Determining the intensity and energy expenditure during commuter cycling. *Br J Sports Med,* 41, 8-12.

Department of Communications Information Technology and the Arts (2008) Participation in Exercise, Recreation and Sport Annual Report 2007.

Department of Infrastructure, T, Regional Development and Local Government, (2009) Road Deaths Australia: 2008 Statistical Summary. Canberra.

Dingus, TA, Klauer, SG, Neale, VL, Petersen, A, Lee, SE, Sudweeks, J, Perez, MA, Hankey, J, Ramsey, D, Gupta, S, Bucher, C, Doerzaph, ZR, Jermeland, J & Knipling, RR (2006) The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment. Virginia, Virginia Tech Transportation Institute.

Elvebakk, B & Steiro, T (2009) First principles, second hand: Perceptions and interpretations of vision zero in Norway. *Safety Science,* 47, 958-966.

Herslund, M-B & Jørgensen, NO (2003) Looked-but-failed-to-see-errors in traffic. *Accident Analysis & Prevention,* 35, 885-891.

Johnson, M, Charlton, J & Oxley, J (2010) The application of a naturalistic driving method to investigate on-road cyclist behaviour. *Australian Cycling Conference.* Adelaide, South Australia.

Landis, JR & Koch, GG (1977) The Measurement of Observer Agreement for Categorical Data. *Biometrics,* 33, 159-174.

Larsson, P, Dekker, SWA & Tingvall, C (2010) The need for a systems theory approach to road safety. *Safety Science,* In Press, Corrected Proof.

London Cycling Campaign (2006) Cycling near lorries and HGVs.

McClintock, H & Cleary, J (1996) Cycle facilities and cyclists' safety : Experience from Greater Nottingham and lessons for future cycling provision. *Transport Policy,* 3, 67-77.

Neale, VL, Klauer, SG, Knipling, RR, Dingus, TA, Holbrook, GT & Petersen, A (2002) The 100 Car Naturalistic Driving Study, Phase 1 - Experimental Design. Blacksburg, Virginia, Virginia Tech Transportation Institute.

Pucher, J, Dill, J & Handy, S (2010) Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine,* 50, S106-S125.

Räsänen, M, Koivisto, I & Summala, H (1999) Car Driver and Bicyclist Behavior at Bicycle Crossings Under Different Priority Regulations. *Journal of Safety Research,* 30, 67-77.

Räsänen, M & Summala, H (1998) Attention and expectation problems in bicycle-car collisions: an in-depth study. *Accident Analysis & Prevention,* 30, 657-666.

Sikic, M, Mikocka-Walus, A, Gabbe, BJ, McDermott, FT & Cameron, PA (2009) Bicycle injuries and mortality in Victoria, 2001-2006. *Medical Journal of Australia*, 190, 353-356.

Summala, H, Pasanen, E, Rasanen, M & Sievanen, J (1996) Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis & Prevention*, 28, 147-153.

Summala, H & Rasanen, M (2000) Top-Down and Bottom-Up Processes in Driver Behavior at Roundabouts and Crossroads. *Transportation Human Factors*, 2, 29-37.

Transport for London (2010) Cycle safety/Cycling near lorries. London.

VicRoads (2007) Road to Solo Driving: learning to drive, driving to learn. Kew, Victoria, Roads Corporation Victoria.

VicRoads (2008a) CrashStats user guide, http://crashstat1.roads.vic.gov.au/crashstats/appendices.pdf, Viewed on 2 February 2009.

VicRoads (2008b) Sharing the road with cyclists: a guide for drivers to increase safety. http://www.vicroads.vic.gov.au/NR/rdonlyres/CD732EF8-242F-48E8-9AB5-5B61C4DA30F0/0/STRwithCyclistsApril08.pdf, Viewed 26 March 2010.

VicRoads (2008c) Victoria's Road Safety Strategy: Arrive Alive 2008-2017. Melbourne.

Walker, I (2005) Signals are informative but slow down responses when drivers meet bicyclists at road junctions. *Accident Analysis & Prevention*, 37, 1074-1085.

Walker, I (2007) Drivers overtaking bicyclists: objective data on the effects of riding position, helmet use, vehicle type and apparent gender. *Accident Analysis and Prevention*, 39, 417-25.

Walker, I & Brosnan, M (2007) Drivers' gaze fixations during judgements about a bicyclist's intentions. *Transportation Research Part F: Traffic Psychology and Behaviour*, 10, 90-98.

Chapter 9 Paper 5
Driver knowledge, attitudes and behaviour

Stages 1 and 2 of this doctoral research focused on the observed behaviours of cyclists and drivers. The video footage from the fixed camera observational study and the naturalistic cycling study allowed for close scrutiny of behaviours, free from potential biases related to recall, reporting or subjective interpretation of experiences. However, it was not possible to determine from these methods the underlying reasons or contributing factors for the observed behaviours or the potential influence of other factors.

The findings of the literature review and findings from Stage 1 and Stage 2 research were instrumental in raising questions about the roles of knowledge and attitudes on driver and cyclist behaviour. In particular, questions about knowledge of cycling-related road rules and attitudes towards cyclists and sharing the road with cyclists were particularly pertinent. In Stage 3, presented in this Chapter, aspects of self-reported behaviours, knowledge and attitudes of cyclists and drivers in Australia were investigated to better understand how they impact cyclist safety.

Stage 3 research involved a survey-based study to address the research question:

- *How does driver knowledge and attitude influence their behaviour in relation to cyclist safety?*

9.1 Survey instrument

The survey was developed to investigate driving behaviour, knowledge of cycling-related road rules, attitudes towards cyclists and cycling experience. Initially separate surveys were developed for drivers and cyclists. A pilot study was conducted with ten respondents (five cyclists who were also drivers and five non-cycling drivers) and revealed that most cyclists were also drivers and completing two surveys was too repetitive and burdensome for those cyclist-driver respondents. In response, the survey format was revised and one survey only was available for respondents to complete.

The pilot study was also conducted to ensure appropriate readability, consistency and usability. Suggestions and comments were incorporated. The final survey was structured so that respondents who were not cyclists skipped the section with cycling-specific questions. The survey comprised a total of 84 questions and was organised as described below:

- Introductory pages
    - Explanatory Statement and Informed Consent
- All respondents
    - Driving experiences, including traffic infringements
    - Collision experiences when driving, including collisions involving a cyclist
    - Driving behaviour related to sharing the road with cyclists e.g. clearance distance when overtaking cyclists, indication time prior to turning
    - Knowledge of cycling-related road rules e.g. bike lanes, bike boxes
    - Attitudes towards cyclists and sharing the road with cyclists, e.g. feelings of comfort when driving with cyclists with and without cycling-related line markings
- Cyclists-only
    - On-road cycling experiences including collisions involving vehicles
    - Motivations for riding

    - Behaviour at red lights, including infringement and reasons for infringement
    - Behaviour at cycling related infrastructure
- Barriers to riding
- Suggestions for safer riding
- Demographics

A clear benefit to delivering the survey online was the immediacy of the action for respondents who were able to click the link and immediately complete and submit the survey (Stewart & Williams, 2005). A limitation of the use of online delivery is access to a computer and the internet (Couper, 2008). A hard copy of the survey was therefore made available for those people who did not have access to a computer or to the internet, or who did not wish to use an electronic version of the survey. The survey was launched online on 15 February 2010 and closed on 31 May 2010. In total, 2,522 surveys were received. A hard copy of the survey is included in Appendix 12.4.

9.1.1 Participant recruitment

The survey was available via the SurveyMonkey website and the web address was advertised on several websites. At Monash University, the link was added to the university homepage and the university's intranet site. The link was also posted at the website for the Monash University Accident Research Centre and the Amy Gillett Foundation's social networking site (Facebook). In addition, the researcher publicised the study in a radio interview (ABC radio, Melbourne).

The 'snowballing' recruitment method was also utilised (Wasserman & Faust, 1995; Atkinson & Flint, 2001). Snowballing relies on identifying potential respondents who then refer the details of the study on to others in their group (Atkinson & Flint, 2001). A study invitation email was sent to participants from the naturalistic cycling study, both the pilot study and the main study. These participants were asked to forward the link to people they thought might be interested in the study, who could then also forward the link and so on. Reports were received informing the researcher that the link had been forwarded to bicycle advocacy groups, to the mailing list of bicycle user groups and included on websites of cycling interest. It is likely that this high exposure amongst groups with a cycling interest was a key reason for the high proportion of surveys received from cyclists.

9.1.2 Participants

The survey was open to all adults aged 18 years and older ensuring that respondents from all jurisdictions would be of legal driving age. A self-selection approach was used for participant recruitment. Use of participant self-selection has the advantage of optimising the number of survey responses, however, the disadvantage of this method is that the sample is less likely to be representative and the findings may therefore have more limited generalisability (Smith, 2001). Nevertheless, this method was chosen as the most appropriate recruitment method for the targeted sample.

9.1.3 Biases

There were two potential biases in this stage. This first related to respondents of the survey and the second, to address the potential biases of the two earlier research stages.

The first potential bias was a response bias related to admission of unsafe or illegal behaviours. In the survey, participants were asked about their behaviour on roads when driving and/or cycling. Examples of illegal behaviour include traffic infringement received while driving and riding through red lights. It was anticipated that the anonymity of an online response would minimise this potential response bias (Stewart & Williams, 2005).

The second potential bias is the *healthy worker effect* and may have affected the findings of Stage 1 observational study and Stage 2 naturalistic study (Dennerlein & Meeker, 2002). Any cyclist who was not able to ride or did not ride on the road during the data collection period was excluded. In Stage 1, this would have excluded cyclists who may prefer routes with less vehicular traffic or who may have re-routed their commute away from the observed routes due to a previous incident. In Stage 2, the inclusion criteria that required participants to ride 70 per cent of their route on-road would have excluded off-road commuters who still may have ridden a considerable proportion of their commute on the road.

It was anticipated that the healthy worker effect bias would be addressed in Stage 3, the survey. As the survey was delivered online, it could be accessed by all interested people in Australia regardless of their riding status or whether they are able to, or choose not to, ride on the roads. The strengths and limitations of the survey method are discussed in Paper 5 (Section 9.2).

Cyclist red light infringement

Previous research has identified that a cyclist behavioural factor that may be a contributing factor in cyclist-driver collisions is red light infringement (Lawson, 1991; Green, 2003; Schramm et al., 2008). In Stage 1, cyclists' behaviours at red lights were investigated and of 4,225 cyclists observed, only 6.9 per cent of cyclists infringed. In Stage 3, questions about red light infringement behaviour were included in the survey to investigate the behaviour further and determine the reasons why some cyclists infringed.

Preliminary analysis of the survey results from Stage 3 showed over a third (37%) of cyclist respondents reported that they had occasionally infringed at signalised intersections. This is significantly greater than the proportion observed in Stage 1, however it is likely that there are implications given the different research methods used. Of the cyclists who reported that they had infringed, the four most common justifications were: turning left (32.9%); their bicycle did not activate the traffic light sensors (30.1%); pedestrian crossing when no pedestrians were waiting or crossing or when cyclists were using the pedestrian crossing (24.4%), and; when there was no vehicular traffic (16.1%). It appears from the justifications given for infringement, that in specific circumstances, cyclists do not consider red light infringement to be an unsafe behaviour, each of these justifications are discussed briefly below.

Justification for red light infringement – turning left

Almost a third of cyclist respondents in the survey (32.9%) reported that they occasionally rode through a red light to turn left. This confirms findings from the observational study in Stage 1 (Chapter 5) that direction of travel (left turn) was the most significant factor associated with red light infringement. Currently this practice, turning left during the red light phase, is not permitted in Australia however there are some exceptions at signed intersections in the Northern Territory and New South Wales. The behaviour is also legal in some states in the US for drivers and cyclists to turn right (right lane travel) during the red light phase.

There may be cyclist safety benefits in permitting cyclists to turn left during the red light phase. For example, cyclists could move through the intersection ahead of the vehicle traffic. This would reduce the need for cyclists and drivers to negotiate the turn together and reduce potential conflict. Recently, Dominiczak (2010) suggested that permitting cyclists to turn left on red may be a solution to the recent increase in the number of cyclist-heavy vehicle collisions that have resulted in cyclist fatalities in the UK (Dominiczak, 2010).

An additional benefit in permitting cyclists to turn left during a red light phase may be a reduction in cyclist travel time. This may increase the desirability of cycle travel as a faster option, particularly in peak travel times. This in turn may lead to an increase in the number of people cycling and subsequently a strengthening of the safety in numbers effect. A trial could be conducted at signalised intersections. An extensive awareness campaign would need to accompany such a trial with adequate, clear signage on site.

Justification for red light infringement – unable to activate traffic light sensors

Almost a third of cyclist respondents in the Stage 3 survey (30.1%) reported that they infringed at the red light because the sensor embedded in the road surface did not detect their bicycle. In the absence of any vehicular traffic they were unable to change the traffic light from red to green. Respondents also noted that this prompted infringement when riding late at night or early morning when there was no vehicular traffic. This suggests that infrastructure is not well suited to be needs of cyclists.

This justification may be interpreted in two ways. First, that the cyclists are not aware of how to activate the traffic sensors. Many traffic light signals can be activated by cyclists if they ride over the correct location. Given that almost one-third of survey respondents reported that they infringed at the red light because they were unable to activate the signal, it is reasonable to assume that this information of how to activate the signals is not widely known. A simple and cost-effective solution may be to incorporate line markings that have been used in Portland, Oregon in the US. A clearly marked, white painted line with a bicycle symbol is used to indicate where cyclists need to ride over to activate the traffic signal (Dill, 2010). This would increase cyclists' engagement in the road network and may reduce cyclist red light infringement. Such markings may reaffirm to drivers that the road authorities recognise the legitimacy of cyclists as active road users. There needs to be an information/awareness campaign to educate riders about how to use the existing system.

The second way to interpret this justification is that not all embedded sensors are calibrated to detect bicycles. Recalibration of the sensitivity of sensors at those sites to ensure cyclists can activate the signal change and bicycle-inclusive details need to be added to the technical specifications and guidelines for new and upgraded signalised intersections.

Further examples of bicycle-inclusive road design that have been utilised internationally in relation to red lights include early bike phase light that allows cyclists to travel through the intersection ahead of the vehicular traffic (Dill, 2010). Early bike phase lights have been installed at selected intersections in Melbourne, however this is not yet a widespread or standard installation. In Amsterdam, in the Netherlands, pedestrian style push buttons are installed at many intersections, with the button adjacent to the road within easy reach for the cyclist. Cyclists can activate the traffic signal without having to dismount. Internationally there are numerous examples of bicycle-inclusive infrastructure at signalised intersections (Pucher et al., 2010) and represent broad potential for bicycle-inclusive infrastructure in Australia.

Justification for red light infringement – pedestrian crossing, no pedestrians are waiting

Almost a quarter of the cyclist respondents to the Stage 3 survey (24.4%) reported that they infringed at pedestrian crossings when there were no pedestrians waiting or on the crossing. In the pilot study for the Stage 1 observational study (see Chapter 4, Table 4-1), all observed cyclists (n=6) rode through the pedestrian crossing. For all cyclists observed, there were no pedestrians crossing or waiting to cross at the time they infringed.

From a cyclist safety perspective there may be little potential harm from vehicular traffic when infringing at a pedestrian crossing, as all vehicles travel in parallel. However, this behaviour may have safety implications for pedestrians as was the case with the pedestrian fatality following the crash with bunch cyclists in Melbourne (see Chapter 2, Section 2.1.1.2). Cyclist behaviour at pedestrian crossings was not explored in the observational studies of this doctoral research, nor was cyclist-pedestrian crashes. Further research is required into cyclist behaviour at pedestrian crossings and broader cyclist-pedestrian safety issues.

Justification for red light infringement – no traffic

The fourth justification given by cyclist respondents in the Stage 3 survey, and the final reason discussed in this section, is that there was no other traffic (16.1%). This reason was not explained by respondents and may be interpreted in two ways. First, the lack of vehicular traffic meant that the traffic signal sensors were not activated and as discussed above, the cyclists infringed as they were unable to change the traffic light from red to green. However, a second interpretation of this reason may be that as there was no vehicular traffic, the cyclist perceived there to be less risk than if traffic was present. The reason that ‘no traffic’ is justification for some cyclists to infringe at red lights needs to be explored further.

Finally, enforcement is the Safe System Framework component that is important to consider in a discussion of cyclist red light infringement. While there may be some scope to permit cyclists to treat a signalised intersection as a yield in some locations, there continues to be a role for enforcement of penalties for non-compliant cyclists. However, a review of the road rules is also needed to ensure that cyclist penalties have the maximum impact on road user safety and are not simply punitive.

In summary, it may be appropriate in some situations to continue through an intersection against a red traffic light, such as to turn left. Improvements are needed to existing road infrastructure to ensure that it is bicycle-inclusive and cyclists are able to activate green traffic lights through better line marking of sensors or recalibration. More research is needed to explore cyclists’ behaviour at pedestrian lights, broader cyclist-pedestrian safety issues and the role that an absence of vehicular traffic has on cyclist behaviour at red lights. Finally, continued enforcement of cyclists who infringe at red lights is required, however a broader systems review that takes into account the potential safety benefits for cyclists being permitted to ride through some red lights is also needed.

These preliminary findings provide important insights into the reasons why cyclists infringe at red lights and highlight the need for more bicycle-inclusive infrastructure at intersections. It was outside the scope of this thesis to submit a full manuscript of these findings, however further analyses of cyclist red light infringement behaviour and the role of the road network are planned.

Paper 5

In Stage 2, drivers’ behaviour was identified as a key contributing factor in cyclist-driver near-collisions. While the observed behaviours were clearly identifiable from the video footage, it was not possible to determine how drivers’ knowledge of road rules or attitudes towards cyclists and sharing the road with cyclists may have impacted the observed behaviours. This gap was investigated in Paper 5.

The paper presented in this chapter, focused on driving behaviours, knowledge and attitude to determine the role of these factors on cycling safety. In total, 2,024 completed survey responses were received. Of those completed surveys, 1,984 (98.0%) of the respondents had a driver's licence. As this analysis was an investigation of driving behaviours, only the respondents who had a driver's licence were included. It is possible that there are differences in knowledge of road rules and attitudes towards cyclists between respondents with a drivers licence compared to those without a drivers' licence, however this comparison was outside the scope of this analysis.

In Paper 5, the differences between drivers were explored. Respondents were categorised into two groups: drivers who were also cyclists (driver-cyclists) and drivers who did not cycle (drivers). This classification was determined by the respondents answer to the question: 'Do you ride a bicycle?' *Driver-cyclists* rode frequently and *drivers* rode occasionally or did not ride as an adult (may have ridden when a child). Of the 1,984 respondents, the majority were driver-cyclists (80.8%). The rationale for focus of this paper and the specific survey questions that were selected for analysis are provided below, followed by the paper.

Behaviour

The behaviour of cyclists and drivers was the main focus of the doctoral research in Stage 1 and Stage 2. In Stage 2, the majority of collisions and near-collisions (73.9%) identified occurred because a driver had turned left across the path of a cyclist (see Figure 9-1).

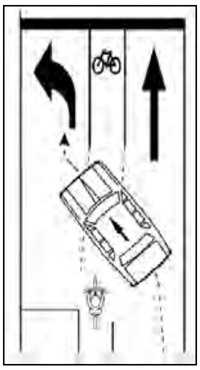

Figure 9-1 Driver left turn across cyclist's path

This behaviour was deconstructed into three component parts: indication time prior to the turning, head check before turning left and overtaking clearance distance when overtaking a cyclist. The underlying factors associated with these three driving behaviours were investigated in the survey and presented in the paper (see Section 9.2).

Knowledge

The questions related to knowledge of road rules focused on two on-road cycling facilities: bike lanes and bike boxes. These are the two most frequently implemented on-road cycling facility in Australia, and are designed and implemented with the intention of creating a designated, safe space for cyclists (VicRoads, 2001; New South Wales Government, 2010). However, little is known about how well these road rules are understood by drivers.

Questions were designed to explore knowledge on two specific rules related to bike lanes. Respondents were asked if they knew that drivers were permitted to: i) travel in a bike lane for up to 50m to manoeuvre around a vehicle; and, ii) enter/cross a dashed bike lane. Given that drivers are permitted to turn left across a bike lane in front of cyclists as in the scenarios presented. These questions are also applicable to drivers' left turn behaviour.

In Stage 1 of this doctoral research, almost half of the observed drivers (49.7%) were non-compliant at bike boxes at signalised intersections (Chapter 6, Publication 2). It was suggested that driver non-compliance may be because drivers were not aware of the road rules that: drivers must keep the bike box clear, even if turning left. Driver knowledge of the road rules related to bike boxes was explored in the survey and is reported in the paper presented in this chapter (Section 9.2).

Attitudes

In addition to knowledge of road rules, attitudes towards cyclists are also highly likely to influence drivers' behaviour on the road when cyclists are present. The evidence regarding attitudes towards cyclists is limited and unclear. For example, there are reports that drivers are ambivalent to cyclists. Research in the UK suggests that, unprompted, drivers were unlikely to mention cyclists in a 'negative' scenario on the road and some drivers did not mention cyclists at all (Davies, Halliday, Mayes & Pocock, 1997; Basford et al., 2002). On the other hand, some research suggests that some drivers hold animosity towards cyclists, as they perceive cyclists' presence to reduce space for vehicles on the road (Davies et al., 1997). Positive attitudes towards cyclists are also reportedly and more frequently associated with drivers who also regularly ride a bicycle (Gatersleben & Appleton, 2007). Furthermore, while one of the main components of the safety in numbers theory is that as more people cycle, drivers will be more likely to ride a bike and understand how to safely interact with cyclists on the road (Pucher, Komanoff & Schimek, 1999; Jacobsen, 2003), little is known about the association between attitudes and behaviour on the road.

Attitudes about cycling and sharing the road with cyclists were explored in this paper to determine if there was an association between attitude and self-reported behaviour. Two key attitudinal questions/statements about cyclists were included here. The first was a rating of agreement to the statement that ‘most cyclists ride safely’. The second question focussed on whether drivers thought that cyclists were unpredictable or not on the road.

Previous research has shown that drivers report feeling more comfortable about encountering cyclists on the road when there are cycling-related line markings on the road even if drivers do not understand the purpose of the lines (Basford et al., 2002). In the paper, drivers’ responses to questions relating to their comfort while travelling on the road with cyclists with and without cycling-related line markings were analysed.

Two questions about sharing the road were also included. The first asked if drivers were more cautious when sharing the road with cyclists. The second related to level of frustration when sharing the road with cyclists. In Australia and in countries with low cycling participation rates including the UK and the US, drivers are the dominant road user and cyclists are often referred to as a frustration or nuisance (Pucher et al., 1999; Fincham, 2006; Harkey & Carter, 2006; Smith, Waterman & Ward, 2006). Drivers were asked if repeatedly overtaking a cyclist was frustrating.

Summary

The paper provides new insights and evidence addressing differences in driving behaviour between cyclists who are also drivers and drivers who do not cycle, their knowledge of cycling-related road rules and attitudes towards cycling and sharing the road. At the time of printing, the manuscript of the driving behaviours of cyclists and drivers had been submitted to the peer-reviewed journal, *Social Science and Medicine*. The submitted version of the journal paper is presented in Section 9.3.

Monash University

Declaration for Thesis Chapter 9

9.2 Driver's knowledge, attitude and behaviour

Declaration by candidate

In the case of Chapter 9, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
▪ Concept and design – initial concept, development of study design ▪ Acquisition of data – data collection, data management, supervision of data quality, operation of technical equipment ▪ Analysis and interpretation – statistical analysis, interpretation of analysis ▪ Paper preparation – paper outline, preparation of figures/illustrations, revision/editing for intellectual content	80%

The following co-authors contributed to the work.

Name	Nature of contribution
Dr Jennie Oxley Dr Judith Charlton	▪ Concept and design – initial concept, development of study design, statistical concepts ▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Paper preparation – paper outline, preparation of figures, revision/editing for intellectual content
Dr Stuart Newstead	▪ Analysis and interpretation of data – statistical analysis, interpretation of analysis ▪ Paper preparation – paper outline, preparation of figures, revision/editing for intellectual content

[redacted]

Candidate's signature

20 May 2011

Date

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location: Monash University Accident Research Centre, Clayton campus

[redacted]
Dr Jennifer Oxley — 16/5/11
Date

[redacted]
Dr Stuart Newstead — 16/5/2011
Date

[redacted]
D[redacted]th Charlton — 19/5/2011
Date

Title: Cyclist safety and the role of driver behaviour, knowledge and attitudes

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ABSTRACT

The majority of fatal and serious cyclist crashes in Australia are the result of a collision with a vehicle. Evidence from crash records and real world cycling studies suggests that behavioural factors and interactions between cyclists and drivers play an important role in collision risk. This study used responses from an online survey of Australian drivers who were also cyclists (driver-cyclists) and drivers who did not cycle (drivers), and compared self-reported driving behaviours. Three key driving behaviours were investigated: use of indicators before turning, head checks and provision of 1m clearance when overtaking cyclists. Associations were explored between these behaviours and knowledge of road rules for on-road cycling facilities (bike lanes, bike boxes) and attitudes towards cyclists and sharing the road with cyclists. In total, 1,984 complete responses were analysed. Driver-cyclists were 1.5 times more likely than drivers to report safe driving behaviours related to sharing the roads with cyclists (95% CI: 1.1-1.9, $p<0.01$). Males were less likely than females to report safe driving behaviour (OR:0.73, 95% CI:0.5-0.9, $p<0.01$). Driver-cyclists had better knowledge of the road rules related to bike boxes than drivers; however knowledge of road rules related to bike lanes was low for both groups. Drivers were more likely than driver-cyclists to hold negative attitudes (e.g. cyclists are unpredictable and repeatedly overtaking cyclists is frustrating). Findings from this study highlight the need for increased education and awareness in relation to safe driving behaviour, road rules and attitudes towards cyclists. Specific recommendations are made for approaches to improve safety for cyclists.

Keywords: driver behaviour, cyclist safety, knowledge, attitudes, Australia

RESEARCH HIGHLIGHTS

- Drivers who are regular cyclists are 1.5 times more likely than non-cycling drivers to drive safely when sharing the road with cyclists
- Significant gaps were identified in driver knowledge of cycling-related road rules, regardless of cycling status
- Positive attitudes towards cyclists were correlated with drivers who are also cyclists

INTRODUCTION

Cycling participation is increasing among adult Australians. From 2001 to 2009, the number of people aged over 15 years who cycled increased by 32 per cent (Department of Communications Information Technology and the Arts, 2009). Government policies are supportive of increased cycling for recreation, fitness and as an alternate form of transport (Austroads, 2005; VicRoads, 2008). Given the increased participation, it might be expected that a 'safety in numbers effect' would be evident. This effect proposes that there is a positive association between increased cycling participation and cyclist safety (Jacobsen, 2003; Elvik, 2009). However despite the increased participation in cycling, there has not been a concurrent increase in cyclist safety in Australia. Indeed, the number and rate of cyclist serious injuries has increased substantially over the last decade in Australia. The age-standardised rates of cyclist serious injured in a road vehicle traffic crash increased by 47 per cent from 2000/01 to 2006/07 (Henley & Harrison, 2010).

There is evidence to suggest that behavioural factors (by both drivers and cyclists) play an important role in collision and near collisions. For example, in a recent naturalistic cycling study conducted in Melbourne, Australia, the majority (73.9%) of observed cyclist-driver collisions and near-collisions occurred when the driver turned left across the path of a cyclist (see Figure 1) (Johnson, Charlton, Oxley & Newstead, 2010).

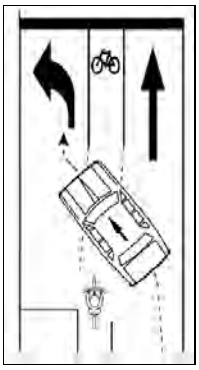

Figure 1 Driver left turn across cyclist's path

There are three component parts to this driver behaviour: indicating prior to turn, head check before turning left and clearance distance provided by the driver when overtaking cyclists (Johnson, Charlton, Oxley et al., 2010). These driver behaviours are likely to be influenced by a range of attitudinal and knowledge factors. Identifying these variables will be critical for elucidating solutions to promote safer driving practices when sharing the road with cyclists.

Previous research has shown that inadequate indicating time for drivers is a contributing factor for cyclist-driver collisions and near-collisions (Rowe, Rowe & Bota, 1995; National Coroners Information System, 2006). In Australia, drivers are required to indicate for a minimum of five seconds before leaving a stationary curbside position or median strip parking (Rule 46(3)) (Australian Transport Council, 1999). At all other times, drivers must give 'sufficient warning' prior to changing direction, however, the duration of a sufficient warning period is not quantified. On road configurations where cyclists travel to the left of vehicles in a parallel (bike) lane, driver left turns without adequate indication will likely require evasive action by the cyclist to avoid the vehicle. This evasive action, which may include rapid braking or swerving, is potentially destabilising and may increase the cyclist's crash risk.

Part of safe turning practice for drivers involves turning their head to check for other road users before making a manoeuvre (VicRoads, 2007). By making a head check, in particular before turning left, drivers are more likely to see a cyclist and avoid a collision (VicRoads, 2007). While head checking (a proxy for looking) is acknowledged as a key behavioural factor in crash causation (Australian Transport Safety Bureau, 2006), the empirical evidence linking this behaviour and crashes is limited and there has been little research to identify characteristics of drivers who fail to head check.

Inadequate clearance distance when overtaking cyclists has also been shown to contribute to increased collision risk for cyclists (McCarthy & Gilbert, 1996). Observations of overtaking situations in the UK showed wide variation in overtaking distance by drivers; the greatest clearance distance was approximately four metres while in some instances, no clearance was given resulting in collisions with the passing vehicle (Walker, 2007). In Australia, there is no legal requirement about the clearance distance that a driver needs to provide when overtaking a cyclist. State and territory governments have made recommendations from at least one metre (1m) (VicRoads, 2007) to two metres in higher speed zones (over 70km/h)(Department of Transport, 2010).

Numerous on-road cycling facilities have been introduced worldwide and in Australia with the aim of creating a designated space for cyclists that segregates drivers from cyclists (VicRoads, 2001; New South Wales Government, 2010). Bike lanes are the most widely implemented on-road cycling facility in Australia and are typically delineated by a white painted line, with an occasional painted bicycle symbol in the lane. Drivers are permitted to use the space: drivers can travel in a bike lane for up to 50m to manoeuvre around a turning vehicle; and drivers can enter/cross a dashed bike lane.

Another common facility installed at signalised intersections in urban areas is the bike box (also known as bicycle storage box, advanced stop line or head start area). This facility originated in the Netherlands and the purpose of this facility is to create a separate space at signalised intersections for cyclists to wait during the red light phase (Pucher, Dill & Handy, 2010). The facility allows cyclists to wait in front of vehicular traffic and away from exhaust fumes, and positions cyclists so that they can enter the intersection first and gain their balance and momentum (Daff & Barton, 2005). This position, ahead of vehicular traffic, is also considered to increase cyclists' conspicuity and driver awareness (McClintock & Cleary, 1996; Pucher et al., 2010) (see Figure 2).

Figure 2 Bike box

While these facilities are designed to provide a designated space for cyclists, they are only effective if drivers do not encroach inappropriately on the spaces provided for cyclists. Studies addressing the behaviour of drivers at these facilities highlight mixed success in directing appropriate driver behaviour and that their behaviour is not entirely compliant.

Johnson and colleagues (2010a) investigated driver behaviour at bike box facilities and reported low rates (49.7%) of driver compliance. In New Zealand, there was a reduction in the number of cyclist-driver collisions following the installation of the boxes. However, drivers reported they did not like cyclists being positioned in front of them and were unsure about the purpose and function of the box (Newman, 2002). In the US, research has shown over half the observed drivers encroached into the box (51.9%) (Hunter, 2000). Similarly, in a large observation study in the UK, over a third of cyclists (36%) experienced a vehicle encroaching into the bike box (Allen, Bygrave & Harper, 2005). Recent research by Dill and colleagues in Portland, Oregon showed that 84 percent of drivers understood the purpose of bike boxes, and 94 percent knew they needed to stop behind the box (Dill, Monsere & McNeil, In Press, Corrected Proof). While bike boxes have been widely implemented in urban areas in Australia since the 1990s, there has been little promotion of the rules and intent of these facilities and no research was found that investigated Australian drivers' knowledge of the rules related to bike boxes.

Driver attitudes have been reported to affect driver behaviour towards cyclists, (Miles & Johnson, 2003; Vanlaar, Simpson, Mayhew & Robertson, 2008) and cyclist safety (Aultman-Hall & Hall, 1998). Positive attitudes towards cyclists are most frequently associated with drivers who also cycle (Gatersleben & Appleton, 2007). In Australia, negative driver attitudes towards cyclists have been associated with poorer knowledge of road rules and lower tolerance of cyclists on the roads (Rissel, Campbell, Ashley & Jackson, 2002). In the UK, drivers reportedly consider on-road cyclists with an ‘impatient caution’ (Basford, Reid, Lester, Thomson & Tolmie, 2002:16). Drivers reportedly consider cyclists to be unpredictable, impinge on their space on the road and feel uncomfortable sharing the road with cyclists, particularly when there are no cycling-related line markings on the road (Joshi, Senior & Smith, 2001; Basford et al., 2002).

In summary, the evidence suggests that behavioural factors play a role in collisions between cyclists and drivers. Less is known about the role of attitudes towards cyclists and knowledge of rules around cycling facilities on behaviour and therefore collision risk. One of the main components of the ‘safety in number effect’ is that drivers who are also cyclists will have a greater understanding of cyclist related issues and how to interact safely with cyclists on the road (Jacobsen, 2003; Pucher & Buehler, 2008). While this is intuitive, there is little evidence to support this notion, particularly relating to the underlying knowledge of road rules and attitudes that can determine interactive behaviours on the road. These issues are addressed in this paper. Prevalence of three driving behaviours that have been identified as contributing factors in cyclist-driver crashes: indicating prior to turn, head checks and providing 1m clearance when overtaking (Johnson, Charlton, Oxley et al., 2010) are measured. Self-reported behaviours of Australian drivers who were also cyclists (driver-cyclists) were compared to drivers who did not cycle (drivers) and associations between these behaviours, knowledge and attitudes were explored.

The specific aims of this study were to: 1) identify the differences in behaviour, knowledge of cycling-related road rules and attitudes towards cyclists of Australian drivers who are also cyclists (driver-cyclists) and Australian drivers who do not cycle (drivers); and 2) determine if knowledge of cycling-related road rules and attitudes towards cyclists are associated with driver behaviour.

METHODS

An online survey method was employed to investigate driver behaviour and the influence of knowledge and attitudes on driver behaviour.

Participants

Participants aged 18 years or older took part in this study. Participation was voluntary and no incentive was offered. The Monash University Human Research Ethics Committee approved the study. All potential respondents were provided with an explanation of the study and their informed consent was implied in the submission of the anonymous survey response.

The main recruitment method was online through the use of several websites (Monash University webpage and intranet, Amy Gillett Foundation webpage and social network page). In addition, a snowball recruitment strategy was used, the survey link was sent to participants from previous cycling studies at Monash University Accident Research Centre and they were invited to forward the link. The survey was also publicised in a radio interview (ABC radio, Melbourne).

Online survey

The survey was designed to investigate driving behaviours on the road, knowledge of cycling-related road rules and attitudes towards cyclists and sharing the road. During the development phase, the survey was piloted with cyclists (n=5) and drivers (n=5) aged 18 years or older to assess question clarity. The survey was delivered online using the SurveyMonkey software. A paper copy was available on request but no requests were received. The survey was conducted from February to May 2010.

Data analysis

From a total of 2,024 completed responses, a subset of 1,984 cases was included in the current analyses, that is, only respondents with a current driver's licence. Respondent type (driver-cyclist/driver) was determined based on the response to the question 'Do you ride a bicycle?' *Driver-cyclists* rode regularly and *drivers* rode occasionally or did not ride as an adult (may have ridden when a child). A total of 7 demographic characteristics and 13 survey questions were analysed. The demographic questions included: gender, age group, marital status, work status, educational level, income and driver-cyclists were asked if they have ever been involved in a crash with a vehicle when cycling on the road.

Three of the survey questions related to driver behaviours were included for analysis: 1) how long drivers indicated (signalled) prior to turning. Response options included a range of times from 2 to 10 seconds, 'I don't need to indicate if there is no traffic around' and 'Other' an open-ended option were dichotomised into adequate (5 seconds or more) or inadequate (less than 5 seconds); 2) head check before turning left. Response options were 'Never', 'Sometimes' and 'Always' were dichotomised into yes (always) and no (never, sometimes); and 3) provided 1m clearance distance when overtaking cyclists. Response options included: half a metre, at least 1m, a car width, as well as 'Other' an open-ended option and were dichotomised into yes (at least 1m or greater) and no (less than 1m).

Four questions related to respondents' knowledge of the road rules about cycling-related facilities were considered. The response categories for all questions were 'True', 'False' and 'Don't know'. Questions related to bike lanes were: 1) are drivers permitted to travel in a bike lane for up to 50m to manoeuvre around another vehicle? and 2) can drivers enter/cross a dashed bike lane? Two questions related to bike boxes were: 1) do drivers need to keep the bike box clear? and 2) do drivers need to keep the bike box clear if they were turning left? Responses to these questions were dichotomised into yes (correct response) and no (incorrect response, don't know).

Six of the survey questions included in the analysis were related to respondents' attitudes towards cyclists and sharing the road with cyclists. The response categories for all questions were a 5-point Likert scale from 'Strongly disagree' to 'Strongly Agree'. Attitude-related questions included respondents' views on whether cyclists ride safely; whether cyclists behaviour on the roads is predictable; their level of comfort when driving with cyclists on the road, with and without cycling-related line markings; whether they felt more cautious when driving on the road with cyclists and whether they found it frustrating to repeatedly overtake cyclists. Responses were dichotomised into agree (strongly agree, agree) and disagree (neither agree nor disagree, disagree and strongly disagree).

Respondents' demographic characteristics were summarised using descriptive statistics, cross-tabulated by respondent group (driver-cyclist/driver) and Chi-square tests. Where there were statistically significant differences between the driver-cyclist/driver groups, these differences were controlled for in multivariate analyses. To identify the demographic factors significantly associated with each survey question, a series of binary logistic regression models were constructed.

Finally, to determine whether there was a significant association between self-reported behaviours and respondents' knowledge and attitudes, additional binary logistic regressions models were constructed.

All statistical analyses were conducted using SPSS Version 18. Statistical significance was set at $p \leq 0.05$.

RESULTS

In total, 1,984 completed surveys were received from respondents with a driver's licence. The majority of these respondents were classified as driver-cyclists (80.8%).

Participant demographics

A summary of the demographic characteristics by respondent group (driver-cyclist/driver) is presented in Table 1. The two groups were significantly different ($p<0.01$) across all characteristics analysed. The groups differed by gender; the majority of driver-cyclist respondents were male (72.4%) while the driver respondent group comprised slightly more females (54.5%). Most respondents were: aged between 30-49 years (driver-cyclists: 59.7%; drivers: 48.4%); married/relationship (driver-cyclists: 74.0%; drivers 62.4%); worked full time (driver-cyclists: 78.2%; drivers 65.9%) and had a university degree (driver-cyclists: 51.1%; drivers 44.9%). The annual household income earned was significantly different between groups; the majority of driver-cyclists' income was higher (over $100,000: 56.3%) than the majority of drivers ($40,000-$99,999: 47.9%). Almost half of the driver-cyclists (45.4%) reported that they had been involved in a collision with a vehicle while riding on the road.

Table 1. Descriptive statistics of key demographic characteristics by respondent group (driver-cyclist/driver)

		Respondent group		Total (n=1,984)
		Driver-cyclist (n=1,604)	Driver (n=380)	
Gender*	Female	27.6%	54.5%	32.8%
	Male	72.4%	45.5%	67.2%
Age*	18-29 years	14.7%	24.7%	16.6%
	30-49 years	59.7%	48.4%	57.5%
	50+ years	25.7%	26.8%	25.9%
Marital status*	Single/never married	19.7%	29.4%	21.5%
	Married/relationship	74.0%	62.4%	71.8%
	Other	6.3%	8.2%	6.7%
Work Status*	Work full time	78.2%	65.9%	75.8%
	Work part time	9.7%	15.9%	10.9%
	Student	5.9%	11.6%	7.0%
	Not working/retired	6.2%	6.6%	6.3%

Education*	Secondary	7.7%	12.1%	8.5%
	Technical school or TAFE	12.5%	14.8%	12.9%
	University degree	51.1%	44.9%	49.9%
	Higher degree	28.8%	28.2%	28.7%
Income*	Less than $20,000	2.1%	4.2%	2.5%
	$20,000 - $39,999	4.6%	5.0%	4.7%
	$40,000 - $99,999	37.0%	47.9%	39.1%
	Over $100,000	56.3%	42.9%	53.7%
Cyclist crash involvement with a vehicle		45.4%	-	-

* statistically significant difference between respondent groups, $p<0.01$

All respondents answered questions about driving behaviour, knowledge of road rules and attitudes. The summary descriptive statistics by respondent group, including Chi squared analyses, are presented in Table 2 to Table 4.

Behaviour

Table 2 shows that the majority of driver-cyclists and drivers reported that when driving, they indicate for 5 seconds before turning. Around two thirds of all respondents head checked before making left turns. Slightly more driver-cyclists reported that they head check before turning left when driving (driver-cyclists: 69.3%, drivers: 66.8%), however this effect was not statistically significant (p>0.05). More driver-cyclists were aware of the need to provide at least 1m clearance when overtaking cyclists while driving than drivers (p<0.01).

Table 2. Summary of behaviour when driving by respondent group (driver-cyclist/driver)

	% respondents		$\chi2$
	Driver-cyclist	Driver	
Indicate for 5 seconds before turning	88.8%	88.7%	0.003
Head check before turning left	69.3%	66.8%	0.840
Provide at least 1m clearance when overtaking cyclist	93.3%	85.3%	26.506*

* statistically significant difference between respondent groups, $p<0.01$

Knowledge

Table 3 presents knowledge of road rules and shows that only a quarter of all respondents (driver-cyclists: 25.9%, drivers 26.1%) reported knowing the Australian regulations permitting drivers to drive in a bike lane for up to 50m to manoeuvre around a vehicle. Almost two thirds of respondents knew that drivers may enter/cross a dashed bike lane (driver-cyclists: 62.5%, drivers 62.4%). Group differences were not significant (p>0.05).

In relation to bicycle facilities at signalised intersections, Table 3 shows that the majority of driver-cyclists and drivers were aware that drivers are required by law to keep the bike box clear (driver-cyclists: 92.5%, drivers: 83.2%), even when the driver is turning left (driver-cyclists: 91.0%, driver: 79.5%) (p's <0.01).

Table 3. Summary of knowledge of road rules by respondent group (driver-cyclist/driver)

	% respondents correct		$\chi 2$
	Driver-cyclist	Driver	
Drivers permitted to travel in bike lane for up to 50m to manoeuvre around turning vehicle	25.9%	26.1%	0.005
Drivers can enter/cross a dashed bike lane	62.5%	62.4%	0.003
Drivers must keep bike box clear	92.5%	83.2%	31.416*
Drivers must keep bike box clear even if turning left	91.0%	79.5%	40.629*

* statistically significant difference between respondent groups, p <0.01

Attitudes

Respondents were asked about their attitudes towards cyclists and sharing the road with cyclists. As shown in Table 4, more driver-cyclists than drivers held the view that most cyclists ride safely (driver-cyclists: 81.0%, drivers: 65.0%) and more drivers than driver-cyclists reported that cyclists were unpredictable (drivers: 40.0%, driver-cyclists: 19.1%) (p<0.01).

Significant group differences were found in levels of comfort about sharing the road with cyclists while driving on roads with and without cycling-related line markings. Fewer than half of the drivers agreed they were comfortable sharing roads without cycling-related line markings, while driver-cyclists were more likely to report being comfortable sharing the roads with cyclists when no markings are present (no lines: drivers: 45.0%, driver-cyclists: 71.1%: p<0.01). The majority of both groups were comfortable sharing the road with cycling-related line markings (with lines: drivers: 78.7%, driver-cyclists: 91.5%; p<0.01).

Table 4 also shows that when driving, both driver-cyclists (92.3%) and drivers (91.8%) were more cautious when cyclists were on the road (p>0.05). Repeated overtaking of cyclists was a source of frustration for the minority of respondents, with drivers (30.5%) significantly more likely to be frustrated than driver-cyclists (13.2%) (p's<0.01).

Table 4. Summary of attitudes by respondent group (driver-cyclist/driver)

		% respondents in agreement		χ^2
		Driver-cyclist	Driver	
About cyclists:	Most cyclists ride safely	81.0%	65.0%	46.064*
	I think cyclists are unpredictable	19.1%	40.0%	75.178*
Comfortable driving with cyclists with:	With on-road cycling-related line markings	91.5%	78.7%	51.260*
	Without on-road cycling-related line markings	71.1%	45.0%	93.683*
When driving:	More cautious when cyclists are on the road	92.3%	91.8%	0.780
	Repeatedly overtaking cyclist is frustrating	13.2%	30.5%	67.351*

* statistically significant difference between respondent groups, $p<0.01$

Factors associated with behaviour, knowledge and attitude

Binary logistic regression models were constructed to determine the association between respondent characteristics and behaviour, knowledge and attitude. In light of observed differences in demographic characteristics between the respondent groups (see Table 1), it was appropriate to control for these variables in the analyses.

Separate logistic regression models were constructed for each of the survey questions tabled above to explore the association with respondent characteristics. In addition to the three driver behaviours, a fourth model was constructed with all three behaviour responses aggregated where a correct response was only recorded if all three component behaviours responses were correct. A summary of the regression models including all significant factors is presented in Table 5.

First, responses relating to respondents' behaviour were considered. Drivers' use of indicators prior to turning was significantly associated with gender; males were less likely to indicate for 5 seconds than females (OR: 0.61, 95% CI:0.4-0.8). No factor was associated with head checking prior to left turn manoeuvres. Overtaking clearance was found to be associated with respondent group with driver-cyclists 2.5 times more likely than drivers to provide at least 1m clearance when overtaking cyclists (95% CI: 1.6-3.9). For the combined driver behaviour model, gender was significant with males less likely to report safe driving behaviour than females (OR:0.73, 95% CI:0.5-0.9). Respondent group was also significantly associated with the combined measure of safe behaviour, with driver-cyclists 1.5 times more likely to report safe driving behaviour than drivers (95% CI:1.1-1.9).

Analyses of knowledge relating to bike lanes and bike boxes highlighted a number of associations between road rules and specific variables of interest. Gender was significantly associated with road rule knowledge. The odds of males reporting knowing that drivers are permitted to travel in a bike lane for up to 50m to manoeuvre around another vehicle was 1.6 times greater than for females (95% CI:1.2-2.1). In addition, males were 1.3 more likely than females to report knowing that they could enter/cross a dashed bike lane (95% CI:1.0-1.6).

In relation to the road rule that drivers need to keep the bike box clear, driver-cyclists were more likely than drivers to know this rule (OR:2.2, 95% CI:1.4-3.3). Age was also a significant determinant: the odds of younger respondents (18-29 years) knowing the road rule was less than that of older respondents, aged 30-49 years (OR:0.39, 95% CI:0.2-0.7) or aged 50+ years (OR:0.28, 95% CI:0.1-0.5). Furthermore, driver-cyclists who had been involved in a crash when riding were more likely to know this rule than driver-cyclists who had not been involved in a crash when riding (OR:1.5, 95% CI:1.0-2.2).

Respondent group and age group were significantly associated with knowledge of driver regulations about bike boxes. Driver-cyclists were more likely to know that bike boxes needed to be kept clear than drivers (OR:2.2, 95% CI:1.4-3.3). Driver-cyclists were also more likely to know that bike boxes must be kept clear even when turning left than drivers (OR:2.1, 95% CI:1.4-3.1). Age was a significant factor as older respondents (30+ years) were less likely than younger respondents (18-29 years) to know the rules about keeping bike boxes clear. As indicated by the odds ratio which was less than 1 and noting that the outcome variable has knowledge as the success category (30-49 years, OR:0.39, 95% CI:0.2-0.7; 50+ years, OR:0.28, 95% CI: 0.1-0.5). Older respondents were also less likely to know the rule about keeping the bike box clear when turning left than younger respondents (30-49 years, OR:0.53, 95% CI: 0.3-0.9; 50+ years, OR:0.43, 95% CI: 0.2-0.8).

After adjusting for all other variables, respondent group remained significantly associated with the driver attitudes of interest. Driver-cyclists were more likely than drivers to agree that most cyclists ride safely (OR: 2.1, 95% CI: 1.5-2.8).

Driver-cyclists were also twice at likely as drivers to agree that they felt comfortable sharing the road with cyclists when driving on roads with cycling-related line markings (OR:2.1-95% CI:1.4-3.1) or without cycling-related line markings (OR:2.0, 95% CI:1.5-2.6). Gender was also significantly associated with comfort, with males more likely than females to feel comfortable sharing the road when there are no cycling-related line markings present (OR: 2.1, 95% CI:1.7-2.7). Driver-cyclists who had been involved in a crash when riding were more comfortable than cyclists who had not had a crash while riding (OR:1.2, 95% CI:1.0-1.5).

Drivers' cautiousness when driving while cyclists are on the road was significantly associated with involvement in a cyclist-related crash. The odds of a crash-involved driver-cyclist being more cautious when sharing the road with cyclists were 60% less than that of a driver-cyclist who had not been involved in a crash (OR:0.60, 95% CI:0.4-0.7).

Drivers were more likely to agree with the 'negative' attitudes than driver-cyclists. The odds of driver-cyclists agreeing that cyclists were unpredictable was 54 per cent less than that of drivers (OR:0.46, 95% CI:0.3-0.6). Driver- cyclists were also less likely than drivers to agree that repeatedly overtaking cyclists was frustrating (OR:0.53, 95% CI:0.3-0.7). In addition, age group was significantly associated with experiencing frustration about repeatedly overtaking cyclists, with younger drivers (18-29 years) less likely than all other age groups to report being frustrated (30-49yrs, OR:0.60, 95% CI:0.4-0.8; 50+yrs, OR:0.46, 95% CI:0.2-0.7).

Table 5. Driving behaviour, knowledge and attitudes – Relative odds of respondent characteristics in the model (statistically significant factors only)

	Predictive factors (stat. sig. only)	Adj. Rel. odds of correct/agree	95% C.I. for odds	Stat. sig.
Behaviour				
Indicate for 5 seconds before	Gender Male vs female	0.616	0.428 – 0.887	<0.01

turning				
Provide at least 1m clearance when overtaking cyclist	Respondent group Driver-cyclist vs driver	2.575	1.678 – 3.951	<0.01
All behaviour	Gender Male vs female	0.733	0.587 – 0.916	<0.01
	Respondent group Driver-cyclist vs driver	1.507	1.141 – 1.991	<0.01
Knowledge				
Drivers permitted to travel in bike lane for up to 50m to manoeuvre around turning vehicle	Gender Male vs female	1.625	1.249 – 2.115	<0.01
Drivers can enter/cross a dashed bike lane	Gender Male vs female	1.314	1.050 – 1.643	0.01
Drivers must keep bike box clear at all times	Respondent group Driver-cyclist vs driver	2.238	1.478 – 3.390	<0.01
	Age			
	30-49 vs 18-29	0.391	0.21 – 0.763	<0.01
	50+ vs 18-29	0.286	0.136 – 0.599	<0.01
	Cyclist crash involvement Yes vs No	1.553	1.079 – 2.248	0.02
Drivers must keep bike box clear even if turning left	Respondent group Driver-cyclist vs driver	2.150	1.467 – 3.153	<0.01
	Age			
	30-49 vs 18-29	0.536	0.310 – 0.928	0.02
	50+ vs 18-29	0.431	0.230 – 0.806	<0.01
Attitude				
About cyclists:				
Most cyclists ride safely	Respondent group Driver-cyclist vs driver	2.114	1.553 – 2.876	<0.01
Most cyclists are unpredictable	Respondent group Driver-cyclist vs driver	0.465	0.343 – 0.630	<0.01

Comfortable driving with cyclists with:				
With on-road cycling-related line markings	Respondent group Driver-cyclist vs driver	2.136	1.437 – 3.175	<0.01
No cycling-related line markings	Respondent group Driver-cyclist vs driver	2.026	1.522 – 2.697	<0.01
	Gender Male vs female	2.149	1.708 – 2.705	<0.01
	Cyclist crash involvement Yes vs No	1.276	1.022 – 1.591	0.03
When driving:				
More cautious when cyclists are on the road	Cyclist crash involvement Yes vs No	0.603	0.416 – 0.784	<0.01
Repeatedly overtaking cyclist is frustrating	Respondent group Driver-cyclist vs driver	0.530	0.374 – 0.752	<0.01
	Age 30-49 vs 18-29	0.606	0.408 – 0.899	0.01
	50+ vs 18-29	0.469	0.284 – 0.774	<0.01

Relationship between behaviour, knowledge and attitude

A series of binary logistic regression models were constructed to explore the association between these behaviours and respondents' knowledge and attitude. Separate models were constructed for each of the three behaviours: indicate 5 seconds before turning, head check before turning left, provide at least 1m clearance when overtaking cyclists. A fourth model was constructed with an aggregated behaviour response (i.e. correct responses for all three behaviours). A summary of the regression models including all significant factors is presented in Table 6.

Analyses revealed significant associations between respondents' use of indicator before turning and two attitude statements. Respondents who were comfortable sharing the road with cyclists without cycling-related line markings were less likely to use indicators appropriately than respondents who were not comfortable on roads without this facility (OR:0.67, 95% CI:0.4-0.9). In addition, respondents who were cautious when sharing the road were more likely to use their indicators appropriately than respondents who reported they were not cautious (OR:1.6, 95% CI:1.0-2.5). Head checking before turning left was significantly associated with being comfortable sharing the road without cycling-related line markings (OR:1.2, 95% CI:1.0-1.6). Driver provision of 1 metre clearance when overtaking cyclists was associated with knowledge that drivers could enter/cross a dashed bike lane (OR:1.4, 95% CI 1.0-2.0).

For the model examining all three behaviours combined, one attitude response was found to be significantly associated with safe driving: respondents who were frustrated by having to repeatedly overtake cyclists were less likely than respondents who were not frustrated to report safe driving behaviour (OR:0.75, 95% CI:0.5-0.9).

Table 6. Driving behaviour – Relative odds of knowledge and attitude responses in the model (statistically significant factors only)

Survey question	Predictive factors (stat. sig. only)	Adj. Rel. odds of correct/agree	95% C.I. for odds	Stat. sig.
Behaviour				
Indicate for 5 seconds before turning	Attitude: comfortable without cycling-related line markings Yes vs No	0.673	0.477 – 0.949	0.02
	Attitude: cautious Yes vs No	1.622	1.032 – 2.548	0.03
Head check before turning left	Attitude: comfortable without cycling-related line markings Yes vs No	1.290	1.038 – 1.604	0.02
Provide at least 1m clearance when overtaking cyclist	Knowledge: dashed bike lane Yes vs No	1.481	1.066 – 2.059	0.01
All behaviour	Attitude: repeatedly overtaking cyclists is frustrating Yes vs No	0.751	0.584 – 0.966	0.02

DISCUSSION

This study investigated the behaviour, knowledge of cycling-related road rules and attitudes towards cyclists of drivers who are also regular cyclists (driver-cyclists) and drivers who do not cycle (drivers) using an online survey. The findings showed that drivers who regularly cycled were more likely to report safer driving behaviour, had greater awareness of the road rules related to bike boxes and were more likely to agree with positive attitudinal statements related to cyclists than drivers who did not cycle regularly. Safer driver behaviour was also associated with gender (female), knowledge that drivers are permitted to cross/enter dashed bike lane and attitudes about comfortability sharing the roads with cyclists on roads without cycling-related line markings. In general, the results are compatible with other studies indicating the driver-cyclists are more likely than non-cycling drivers to report safe driving behaviours (Jacobsen, 2003; Pucher & Buehler, 2008) and positive attitudes towards cyclists (Gatersleben & Appleton, 2007).

Analysis of respondent group differences revealed that driver-cyclists were significantly more likely than drivers to report safe driving behaviour and more than twice as likely as drivers to report provision of 1m clearance when overtaking cyclists. Findings relating to driver attitudes also showed that driver-cyclists were more likely to agree with positive attitudinal statements about cyclists. Driver-cyclists were more likely to believe that most cyclists ride safely and they were more likely to be comfortable sharing the road with cyclists while driving, with or without cycling-related line markings. Driver-cyclists and drivers also differed with respect to knowledge of cycling-facilities related road law. Driver-cyclists were more likely to know the road rules related to keeping bike boxes clear, even when turning left. A similar proportion of respondents knew the rules that drivers were permitted to enter/cross a dashed bike lane. However, a relatively low proportion of respondents in both driver-cyclists and driver groups were familiar with the road rules related to bike lanes. This is of concern given the extensive implementation of bike lanes in urban areas, given that the intention of these facilities is to create space for cyclists and therefore improve cyclist safety.

Findings from this study are supportive of the concept of safety in numbers which proposes a positive association between cycling participation and cyclist safety (Jacobsen, 2003; Pucher & Buehler, 2008; Elvik, 2009). Driver-cyclists were found to have a greater understanding of cycling related road rules and how to interact safely with cyclists on the road than drivers who do not cycle. Despite the relatively low number of cyclists in Australia, recent increases in cycling participation and rising numbers of serious cyclist crashes in Australia (Henley & Harrison, 2010), indicative of a negative association, findings from this study suggest that cycling participation has a positive influence on driver behaviour, knowledge and attitudes towards cyclists.

A number of driver characteristics were found to influence selected driving behaviours important for cyclist safety. While the majority of drivers reported appropriate use of indicators when turning (particularly females), it was of some concern that a small proportion of respondents (3.0%) who reported rarely or seldom indicating when undertaking turning manoeuvres and reported not indicating at all if there was no other traffic. In previous research, lack of adequate indication time prior to turning was reported to be a significant predictor of cyclist-driver near-collisions (Johnson, Charlton, Oxley et al., 2010). Without adequate signalling, a cyclist travelling in parallel with vehicular traffic may not have sufficient time to safely reduce their speed to avoid the turning vehicle. Rapid, evasive manoeuvring may be destabilising for the cyclist, and swerving away from the turning vehicle may increase the risk of a crash.

The findings that significant proportions of cyclists and drivers did not head check prior to turning left are consistent with previous research on drivers' looking behaviour and visual search strategies indicating that drivers are more focused on the direction of traffic from the direction of greater threat (i.e. in Australia, traffic from the right) (Summala et al., 1996, Summala and Rasanen, 2000). This may result in a reduced likelihood of drivers look/check to their left prior to turning as there is no vehicular threat to their safety from that direction.

The findings from this study are of particular concern in light of evidence from our previous research which identified that near-collisions between cyclists and drivers were associated with drivers turning left across the cyclists' paths and without adequate indication (Johnson, Charlton, Oxley et al., 2010). A promising approach to modify this unsafe turning practice comes from research in Finland which shows that drivers' head check behaviour on approach to intersections increases when speed limits are lowered (Summala, Pasanen, Räsänen & Sievanen, 1996). Further research is needed to determine an effective countermeasure for Australian roads to increase driver left head check behaviour prior to turning, including lower speeds.

The majority of all respondents (91.8%) were aware of the recommendation when driving of providing at least 1m clearance when overtaking cyclists. Recently, the Amy

Gillett Foundation addressed the need for drivers to provide 1m clearance when overtaking cyclists in an education/awareness campaign called *A Metre Matters* (Amy Gillett Foundation, 2009). The Australia-wide campaign includes an illustrative logo that has been used in public displays including billboards (see Figure 3).

Figure 3 A metre matters campaign logo
Amy Gillett Foundation, 2009, reproduced with permission

While it is not possible to attribute driver attitudes and awareness of the need for this behaviour with the timing and content of this campaign, it is interesting to note that cyclist-drivers in the current study were more likely than drivers to know about this requirement. This behaviour may be due to cyclists' personal experiences on the road and a heightened awareness of the importance of sufficient clearance.

This study also provided important insights on the association between the three driving behaviours of interest and drivers' knowledge and attitudes. Two of the attitude statements were associated with appropriate indication before turning left behaviour: respondents who felt uncomfortable travelling sharing the road with cyclists when there were no cycling-related line markings; and respondents who felt more cautious when sharing the road with cyclists. Intuitively, these findings appear to be positive for cyclist safety, as they suggest that when drivers feel uncomfortable or cautious, they are more likely to indicate important signalling information to cyclists. However, arguably, the safety of cyclists depends on appropriate use of indicators by *all* drivers and more research is needed to gain a greater understanding of the underlying factors for this behaviour to ensure wider adoption of safe turning behaviour.

In contrast, respondents who felt comfortable sharing the road without cycling-related line markings were more likely to head check before turning left. Curiously, this group were less likely to indicate before turning but engaged in head checking behaviour. The explanation for this apparent mismatch is not clear. An association was also shown between knowledge of the road rule related to the dashed bike lane and providing at least 1m clearance when overtaking cyclists.

The combined behaviour variable was inversely associated with frustration with repeatedly overtaking cyclists. This finding is of concern, as it suggests that frustrated drivers are less likely to practice safe driving behaviour when interacting with cyclists. It is important that driver frustration is reduced through the introduction of intuitive cycling facilities that allow cyclists and drivers to travel in parallel and that road design minimises points of competition or leapfrogging behaviour on the road.

Despite the widespread implementation of on-road bike lane facilities in Australia, this study showed varied level of awareness amongst cyclists and drivers about two important road rules related to bike lanes. These findings have serious safety implications for cyclists. Cyclists who are unaware of these rules may not anticipate drivers entering the bike lane to manoeuvre around a turning vehicle. While drivers who are unaware of the rule may drive in the bike lane further than the 50m, effectively using the bike lane as an additional vehicle lane and this may increase cyclists' exposure to risk. Increased awareness of these road rules is needed among both drivers and cyclists. In contrast to knowledge of the rule relating to travel in bike lanes, there was greater awareness amongst both driver-cyclists and drivers about the road rules related to crossing over dashed bike lanes. Almost two thirds of all respondents were aware of the rule and females were more likely than males to know this rule.

Overall, respondents' knowledge of bike box rules was generally high compared with knowledge of bike lane use. More driver-cyclists than drivers had a sound knowledge of bike box rules. This is not surprising as the intention of the facility is to create a designated space for cyclists. Bike boxes have been implemented in Australia since the 1990s (Daff & Barton, 2005) and while there are details about the road rules available on the government road authorities websites, the rules about interacting with cyclists within the space are not explicitly stated in drivers' licence handbooks (VicRoads, 2007) and there has been little public education on these rules. Younger respondents (18-29 years) were also more likely than older respondents (30+ years) to know the laws on bike box. The explanation for this age effect is not clear, however, it is possible that age differences in knowledge of rules may be related to differences in cycling experiences.

The relatively high level of knowledge of the bike box rules amongst respondents in this study stands in contrast to our previous research indicating low levels of observed driver compliance at these facilities (Johnson, Charlton, Newstead & Oxley, 2010). Together, these findings suggest that knowledge does not necessarily translate to compliant behaviour (Hunter, 2000; Newman, 2002; Allen et al., 2005; Johnson, Charlton, Newstead et al., 2010).

Drivers reported that that they were frustrated by repeatedly overtaking cyclists. While the location on the road of this behaviour was not specified, it is possible that this behaviour is an unforeseen consequence of bike boxes that encourages repeated 'leap frogging' of cyclists and drivers between midblock and intersections and increase drivers' frustration. It may be that alternative lane markings, such as continuous bike lanes that allow drivers and cyclists to continue in parallel may reduce driver frustration.

Greater educational efforts are needed to increase driver knowledge of rules for cycling-related facilities. In addition, there may be a need for increased enforcement to improve driver compliance to ensure that bike boxes do indeed provide a safe space for cyclists.

There were significant differences between driver-cyclists and drivers for most of the attitude statements considered in this study. Driver-cyclists agreed that most cyclists ride safely. This is not a surprising result, because by definition, driver-cyclists in this study had more direct experience than drivers of travelling on the road on a bicycle. Driver-cyclists also felt more comfortable sharing the road with cyclists while driving, with and without cycling-related line markings. This higher comfort level may stem from experience as a driver who is also a cyclist, may be more aware of the hazards on the road for a cyclist and so find cyclists' behaviour more predictable (Jacobsen, 2003). These findings confirm earlier research that positive attitudes towards cyclists are most frequently associated with drivers who are also cyclists (Gatersleben & Appleton, 2007).

Drivers were more likely than driver-cyclists to agree with the 'negative' attitude questions. More drivers agreed that cyclist were unpredictable and that repeatedly overtaking cyclists was frustrating. It is possible that there is an association between drivers' attitudes and their lack of cycling experience. This may be addressed by increasing cycling participation and therefore drivers' empathy with cyclists' perspective. However, it is important to recognise that not all drivers will want to, or be able to, ride a bicycle on the road. Therefore, it will be important to identify ways of raising awareness amongst all drivers about safe driving behaviours when sharing the road with cyclists, regardless of drivers' cycling status. Furthermore, it may be that cyclists' own unsafe and/or illegal behaviour may also contribute to drivers' attitudes.

More research is needed to explore the link between driver negative attitude towards cyclists and lack of knowledge of cycling-related road rules and unsafe driving behaviours. Observational studies of real-world driving will be useful to elucidate whether driver frustration with repeatedly overtaking cyclists plays leads to drivers overtaking too closely. A greater understanding of the role of driver attitude and knowledge on safe driving behaviours when sharing the roads with cyclists is important to inform targeted countermeasures to improve cyclist safety.

Strengths and Limitations

This study provides new insights about driving behaviours in relation to safely interacting with cyclists on the road. The survey provided an opportunity to explore in greater depth the attitudes and knowledge related to the behaviour observed in previous studies. The associations identified between behaviours, knowledge and attitudes may assist the development of more targeted education and awareness campaigns to improve driver behaviour and increase cyclist safety.

Methodological limitations were primarily related to potential sampling bias. Given the lack of accurate data in Australia on the numbers of cyclists and profiles of cyclists, it is difficult to determine the representativeness of the study samples. Similarly, it is difficult to disaggregate the driving population into cycling and non-cycling groups. Improved cyclist profile data is needed to ensure future data accurately represents the cycling and non-cycling populations.

CONCLUSIONS AND RECOMMENDATIONS

Drivers who are also cyclists are more likely than drivers who are not cyclists to report safe driving behaviours related to sharing the road with cyclists. Given the increasing number of cyclists on the road and the continuing installation of cycling facilities it is important that accurate and timely information is provided to all road users to ensure a high appreciation of the importance of safe behaviour when sharing the road with cyclists. There is a need for increased education about road rules related to on-road cycling facilities and greater understanding is needed of how drivers' attitudes may affect cyclist safety. Gender effects for knowledge of road rules also suggest a need to target females in education/awareness campaigns.

Further research is warranted to identify the specific roadway locations and road types where overtaking collisions and near-collisions occur. It is possible that road design influences this type of behaviour, particularly at points where the road narrows. Findings from this study underscore the need for driver education about waiting to overtake cyclists until there is sufficient space on the road to do so safely. Similarly, there may be a need for education of cyclists about positioning themselves on the road where they can safely travel with drivers, be seen and allow enough space to be overtaken safely. Finally, understanding of and compliance with cyclist-related road rules may lead to increased predictability and potentially improved safety for all road users.

REFERENCES

Allen, D., Bygrave, S., & Harper, H. (2005). *Behaviour at cycle advanced stop lines*: Transport Research Laboratory.

Amy Gillett Foundation. (2009). *A metre matters*.

Aultman-Hall, L., & Hall, F. L. (1998). Ottawa-Carleton commuter cyclist on-and off-road incident rates. *Accident Analysis and Prevention, 30*(1), 29-43.

Australian Transport Council. (1999). *Australian Road Rules*.

Australian Transport Safety Bureau. (2006). *Deaths of cyclists due to road crashes*: Australian Government.

Austroads. (2005). *The Australian National Cycling Strategy 2005-2010*. Sydney.

Basford, L., Reid, S., Lester, T., Thomson, J., & Tolmie, A. (2002). *Drivers' perceptions of cyclists*: Department for Transport.

Daff, M., & Barton, T. (2005). *Marking Melbourne's Arterial Roads to Assist Cyclists*. Paper presented at the ITE 2005 Annual Meeting and Exhibit. Institute of Transportation Engineers.

Department of Communications Information Technology and the Arts. (2009). *Participation in Exercise, Recreation and Sport Annual Report 2008*. Retrieved. from.

Department of Transport. (2010). *A Handbook for Western Australian Road Users*. Retrieved. from.

Dill, J., Monsere, C. M., & McNeil, N. (In Press, Corrected Proof). Evaluation of bike boxes at signalized intersections. *Accident Analysis & Prevention*.

Elvik, R. (2009). The non-linearity of risk and the promotion of environmentally sustainable transport. *Accident Analysis & Prevention, 41*(4), 849-855.

Gatersleben, B., & Appleton, K. M. (2007). Contemplating cycling to work: Attitudes and perceptions in different stages of change. *Transportation Research Part A: Policy and Practice, 41*(4), 302-312.

Henley, G., & Harrison, J. E. (2010). *Serious injury due to land transport accidents, Australia, 2006-07*. Australian Government: Australian Institute of Health and Welfare,.

Hunter, W. W. (2000). *Evaluation of a Combined Bicycle Lane/Right Turn Lane in Eugene, Oregon*: University of North Carolina, Chapel Hill, Federal Highway Administration.

Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Inj Prev, 9*(3), 205-209.

Johnson, M., Charlton, J., Newstead, S., & Oxley, J. (2010). Painting a designated space: cyclist and driver compliance at cycling infrastructure at intersections. *Journal of the Australasian College of Road Safety, 21*(3).

Johnson, M., Charlton, J., Oxley, J., & Newstead, S. (2010). Naturalistic cycling study: identifying risk factors for on-road commuter cyclists. *Annals Advanced Automotive Medicine, 54*, 275-283.

Joshi, M. S., Senior, V., & Smith, G. P. (2001). A diary study of the risk perceptions of road users. *Health, Risk & Society, 3*(3), 261-279.

McCarthy, M., & Gilbert, K. (1996). Cyclist road deaths in London 1985-1992: drivers, vehicles, manoeuvres and injuries. *Accident Analysis and Prevention, 28*(2), 275-279.
McClintock, H., & Cleary, J. (1996). Cycle facilities and cyclists' safety : Experience from Greater Nottingham and lessons for future cycling provision. *Transport Policy, 3*(1-2), 67-77.
Miles, D. E., & Johnson, G. L. (2003). Aggressive driving behaviors: are there psychological and attitudinal predictors? *Transportation Research Part F: Traffic Psychology and Behaviour, 6*(2), 147-161.
National Coroners Information System. (2006). Fatal Facts: Case study 2 - Bicycle accidents. *July, Edition 10*.
New South Wales Government. (2010). *NSW BikePlan*.
Newman, A. (2002). *The marking of advanced cycle lanes and advanced stop boxes at signalised intersections*. Christchurch.
Pucher, J., & Buehler, R. (2008). Making Cycling Irresistible: Lessons from the Netherlands, Denmark, and Germany. *Transport Reviews, 28*.
Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine, 50*(Supplement 1), S106-S125.
Rissel, C., Campbell, F., Ashley, B., & Jackson, L. (2002). Driver Road Rules Knowledge and Attitudes towards Cyclists. *Australian Journal of Primary Health, 8*(2).
Rowe, B. H., Rowe, A. M., & Bota, G. W. (1995). Bicyclist and environmental factors associated with fatal bicycle-related trauma in Ontario. *Cmaj, 152*(1), 45-53.
Summala, H., Pasanen, E., Räsänen, M., & Sievanen, J. (1996). Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis & Prevention, 28*(2), 147-153.
Vanlaar, W., Simpson, H., Mayhew, D., & Robertson, R. (2008). Aggressive driving: A survey of attitudes, opinions and behaviours. *Journal of Safety Research, 39*, 375-381.
VicRoads. (2001). Cycle Notes No. 9 - Creating On-Road Space for Cyclists.
VicRoads. (2007). *Road to Solo Driving: learning to drive, driving to learn*. Kew, Victoria: Roads Corporation Victoria.
VicRoads. (2008). *Victoria's Road Safety Strategy: Arrive Alive 2008-2017*. Melbourne.
Walker, I. (2007). Drivers overtaking bicyclists: objective data on the effects of riding position, helmet use, vehicle type and apparent gender. *Accident Analysis and Prevention, 39*(2), 417-425.

Chapter 10
Discussion

The overall aim of this doctoral research was to identify characteristics of road users and road system that may contribute to cyclist crash risk. The research investigated cyclist and driver behaviour and how the two groups interact on the road and identified factors that contributed to cyclist-driver near-collisions. The studies were directed by four key research questions:

1. *What are the behaviours and characteristics of road users that place cyclists at risk?*
2. *What is the role of cycling infrastructure/facilities in cyclist-driver interaction and behaviour?*
3. *What contributing factors can be identified in cyclist-driver collision and near collision events?*
4. *How does driver knowledge and attitude influence their behaviour in relation to cyclist safety?*

Each of the research questions was addressed in one or more of the three stages of research. This chapter brings together the findings from Stage 1 observational study, Stage 2 naturalistic cycling study and Stage 3 survey of driver knowledge, attitudes and behaviour. Implications of the findings are discussed with reference to the Safe System Framework. First, a short summary of the main findings is provided here, followed by a comprehensive discussion of specific issues and the implications of the findings.

Overview of key research findings

The primary focus of Stage 1, the fixed camera observational study, was cyclist and driver behaviour at intersections. Intersections were of critical interest because the majority of cyclist fatality and serious injury crashes occur at intersections. The study generated hundreds of hours of video footage observations. The objective was to identify potentially risky cyclist and driver behaviours. No collisions or near-collisions were recorded; however, two key behaviours considered and identified as the most overt risky behaviours and analysed were: cyclist behaviour at red lights, specifically running red lights; and cyclist and driver behaviour at cycling facilities at intersections, specifically compliance in providing a separate space for cyclists.

Findings from fixed camera observations of cyclists at red lights showed that infringements were incurred by 6.9 per cent of the 4,225 cyclists who faced a red light. Predictive factors for infringement were cyclists' direction of travel (left turn) and gender (male). Presence of other road users (drivers and cyclists) had a deterrent effect (Publication 1, Chapter 5).

Analysis of cyclist and driver behaviour at intersections focused on compliance at two cycling facilities: bike box and continuous bike lane. Compliance required cyclists to stop and wait in the designated bicycle-only zones (where available) and drivers to stop and wait outside the designated bicycle-only zones. Cyclists were more likely to be compliant than drivers at the standard bike boxes (cyclists: 64.9%, drivers: 49.8%) and centre bike boxes (cyclists: 53.0%, drivers: 49.6%). The majority of cyclists and drivers were compliant at the continuous bike lanes and were significantly more compliant than at the bike boxes (Publication 2, Chapter 6).

While new and important information was gained from this method of observation about cyclist and driver behaviour at intersections, the fixed camera approach captures a relatively small window on the commuter cyclists' trip. Observations were limited to the selected intersections along routes with high volumes of commuter cyclists, to the exclusion of other intersection types and midblock locations. Further, no collisions or near-collisions were recorded which precluded analysis of contributory factors in cyclist-driver crashes. Thus, analyses were based solely on infringement behaviours of cyclists and drivers which were thought to place cyclists at risk of a crash. Stage 2, the naturalistic cycling study was therefore designed to address these limitations and extend the investigations of cyclist-driver interactions over entire cyclist commuter trips.

In Stage 2, naturalistic driving methods were adapted and piloted for use with cyclists (Publication 3, Chapter 7). Following the successful pilot study, a naturalistic cycling study was conducted with a sample of adult commuter cyclists using helmet-mounted video cameras (Publication 4, Chapter 8). Analyses focused on cyclist-driver interaction events including: collisions (n=2), near-collisions (n=6) and incidents (n=46) and identified contributing factors for those events. A key finding was that drivers were identified as the road users at fault (i.e. their behaviour instigated the unsafe interaction as per the 100-car driving study data dictionary (Dingus et al., 2006)) for 87 per cent of events. The most frequent behaviour associated with near-collision and incident events was drivers turning left across the cyclist's path (73.9%).

The observational studies conducted in Stages 1 and 2 provided new insights into behaviours and characteristics of road users that place cyclists at risk, the role of cycling infrastructure and contributing factors in cyclist-driver collision and near collision events. However, inherently, these covert monitoring methods do not afford insight into road user knowledge and attitudes and how these factors may influence the observed behaviours. This gap was addressed in Stage 3 using survey methods to explore in more depth, road user characteristics relating to the safety of on-road cyclists (Paper 5, Chapter 9).

Survey questions were designed to elicit information which might explain unsafe behaviour leading to near-collisions when drivers turned left across a cyclist's path. This event was of considerable interest because it was found to be the most common type of near-collision/incident event identified in the naturalistic cycling observations. Given its prevalence and risk, this driver behaviour was deconstructed and three components of driving behaviours were analysed: use of indicators before turning, head check before turning left and clearance distance provided when overtaking and compared between two groups, driver-cyclists and non-cycling drivers. Drivers who were also cyclists were 1.5 times more likely than drivers who were not cyclists to report safe driving behaviours when sharing the road with cyclists. While the majority of all respondents knew the road rules related to bike boxes, significant gaps in knowledge were identified in relation to bike lane road rules. Positive attitudes about cyclists and sharing the road were more likely to be associated with drivers who were also cyclists compared to drivers who were not cyclists.

Theoretical framework

The theoretical framework for this doctoral research was the Safe System Framework (SSF) which underpins road safety in Australia (see Chapter 3, Figure 3-2). Researchers have claimed that opportunities for achieving improved cyclist safety in Australia have been a secondary priority and that major transport policies are still heavily dominated by vehicular modes of transport (Garrard et al., 2010). It was important to recognise this driver-dominant context in the current research findings. However, throughout this research a cyclist-inclusive interpretation of the SSF was used. The two SSF components investigated in this doctoral research were safer road users and safer roads and the discussion of the main findings is grouped under these themes. The framework is also used to identify gaps in the current practices and potential solutions for improving cyclist safety.

The following sections of this chapter are structured into four sections. In the first sections, discussion of the findings related to safer road users and safer roads is presented. Next, the limitations of the doctoral research are considered. The closing section provides a summary and reflection on the key findings, safety solutions and directions for future research.

10.1 Safer road users

Fundamental to the safer road users component of the SSF is that all road users are alert, compliant and each individual is responsible for their own actions. The following discussion of the findings related to safer road users is presented in two sections: driver behaviour, knowledge and attitudes; and cyclist behaviour. It is acknowledged that this division is somewhat artificial and is at odds with a systems approach, nevertheless it provides a useful structure to ensure that the perspectives of both road user groups are considered.

10.1.1 Driver behaviour

Drivers were shown to contribute significantly to cyclist collision risk. In this section, key findings related to driver behaviour, and the role of driver knowledge and attitudes are discussed. Driver behaviour at on-road cycling facilities is discussed in Section 10.2 Safer roads.

A key finding of this doctoral research relating to driver behaviour was that drivers' actions contributed to 87 per cent of cyclist-driver near-collisions identified in the naturalistic cycling study (Publication 4, Chapter 8). Drivers' pre-event behaviour was analysed using a modified 100-car study data dictionary (Dingus et al., 2006), drivers' pre-event behaviour was analysed. The most frequent pre-event driver behaviour was turning left across a cyclist's path (73.9%) (see Figure 10-1) (see Chapter 8, Table 2).

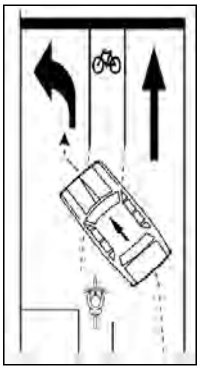

Figure 10-1 Driver left turn across cyclist's path

These findings relating to driver behaviour as a contributing factor in cyclist-driver unsafe interactions are consistent with previous studies reviewed in Chapter 2 (see Table 2-2). In particular, three driver behaviours that had been identified in the previous research, were included in this driver left turn behaviour: inadequate indicator time (National Coroners Information System, 2006), drivers not seeing cyclists (Rowe et al., 1995; McCarthy & Gilbert, 1996; Summala et al., 1996; Räsänen & Summala, 1998, 2000; Herslund & Jørgensen, 2003; Walker, 2005; Australian Transport Safety Bureau, 2006; Schramm et al., 2008) and the clearance distance drivers provide when overtaking cyclists (McCarthy & Gilbert, 1996; Walker, 2007). Given the prominence of drivers turning across cyclists' path in near-collision/incident events, the three component behaviours were investigated in greater detail.

Adequate indication (signalling) prior to turn

Insufficient driver indication prior to turning has been identified in the literature in relation to cyclist crash risk (Rowe et al., 1995; National Coroners Information System, 2006) and this is supported by the findings of the current research. In the naturalistic cycling study, a third of drivers (33.3%) did not indicate prior to turning in front of the cyclist (Table 2, Publication 4) while half (50%) of those who did indicate, did so for only 1-3 seconds. The link between driver indicating behaviour and cyclist safety is discussed in Publication 4 (Chapter 8). As cyclists and drivers usually travel in parallel on the roads, cyclists are dependent on the driver for a cue that they are intending to turn. When there is no cue or only a very short indication before the driver turns, the cyclist may need to react to avoid contact with the vehicle. Typically, observations from the naturalistic study showed that for driver left turn near-collision events, cyclists reacted by braking and/or swerving. Depending on their travel speed, cyclists' avoidance manoeuvres may need to be sudden and forceful and potentially destabilising, which may reduce (other) drivers' ability to predict their path of travel and increase their risk of a collision or a fall.

In Stage 3, drivers' use of indicators before turning was further investigated (Paper 5, Chapter 9). The majority of cyclists and drivers reported that they indicated for 5 seconds before turning (cyclists: 88.8%, drivers: 88.7%). Females were almost twice as likely as males to report that they indicated for at least 5 seconds before turning. However, 11 per cent of respondents reported they indicated for less than 5 seconds before turning.

Differences in drivers' use of adequate signalling may be due to the low likelihood of a vehicle being present to their left. Insufficient warning before turning, especially before turning left across a cyclist's path, is likely to have serious safety implications for cyclists and has been identified in the literature as a contributory factor for cyclist crash risk (Rowe et al., 1995; National Coroners Information System, 2006). Despite the grave safety outcomes of the driver's actions, the Coroner did not explore the role of the truck driver's behaviour in the crash and subsequently, no recommendations or countermeasures that directly related to driver behaviour were identified in Coroner's review.

Australian road rules provide specific guidance around use of indicators and duration of indication (5 seconds) only for manoeuvres involving drivers leaving the curb or a median parking bay (ARR46(3)) (Australian Transport Council, 2009). For all other manoeuvres, such as changing lanes or overtaking, the rules specify that drivers must provide 'sufficient warning'. It is possible that some drivers consider one or two seconds to be sufficient warning. Quantifying 'sufficient warning' in the road rules may provide more clarity for drivers and cyclists and increase drivers' indication time and subsequently the predictability of drivers' direction of travel for cyclists travelling in the parallel bike lane. Such amendments to road rules could be disseminated to new cohorts of learner drivers through the driver's licence handbook, while a broader behaviour change campaign may be required to raise awareness amongst existing drivers. Further research is needed to determine the role of inadequate indication in cyclist-driver crashes and the impact of this specific behaviour on cyclist safety to inform potential countermeasures.

Driver looking behaviour/head checks

Findings from the naturalistic cycling study showed that approximately one third of drivers did not appear to see the cyclist involved in the near-collision event (Publication 4, Chapter 8). The helmet-mounted camera view did not afford direct evidence of driver looking behaviour or head checks. Thus, evidence for 'failure to see' was identified using established criteria from driving studies (Dingus et al., 2006); that is, when the vehicle moved into the lane too closely to the road user who was travelling in that lane. Additional evidence that drivers did not see the cyclist was inferred when there was no observable driver reaction to an impending near collision event. Absence of driver reaction was recorded for 83.3 per cent of the near-collision events. That is, there was no driver action visible in the video footage to suggest the driver had seen the cyclist: the driver did not brake, accelerate or change their course.

Cyclists typically travel on the left (passenger) side of vehicular traffic. From the driver's perspective, the left side is less conspicuous and more difficult to detect, but also less likely to pose a threat from other motor vehicles and as a consequence, drivers may be less likely to head check in this direction (Summala et al., 1996; Summala & Räsänen, 2000; Joshi et al., 2001; van Haeften, 2010). Driver head check behaviour was further investigated in Stage 3, the survey.

In Stage 3, the majority of drivers who were cyclists (69.3%) and non-cycling drivers (66.8%) reported that they head checked to their left before making a left turn (Table 2, Paper 5) while around 30 per cent of respondents reported that they did not head check before turning left. This was a surprising finding, particularly for drivers who were also cyclists, as it might be assumed that when driving, cyclists would be more aware of the vulnerability of cyclists and more familiar with the manoeuvres which place cyclists at risk, and would therefore be more likely to be vigilant in checking for cyclists on the road.

It is essential that drivers check to their left before making a left turn to ensure that when a cyclist is present, there is sufficient space to overtake safely. Previous research in Finland reported a correlation between reduced driver speeds on approach to intersections and increased looking behaviour (Summala et al., 1996; Summala & Räsänen, 2000) and road infrastructure that encourages drivers to reduce speed may be an effective measure to increase driver head check behaviour. Additionally, it will be important to consider the benefits of education and awareness for all drivers for improving driver left head check behaviour.

Clearance distance when overtaking

The third behaviour related to drivers turning across a cyclist's path was inadequate clearance distance when overtaking. Overtaking included situations when a driver passed a cyclist in order to turn left or to merge into the same lane and continue travelling ahead of the cyclist. Evidence for inadequate overtaking clearance was derived indirectly from the observed measures of drivers' behaviour and cyclists' responses during overtaking manoeuvres: the manoeuvre was deemed too close when cyclists braked or swerved in response to the passing vehicle. In over half of the events identified in Stage 2 (55.5%), drivers were observed to turn or merge too closely in front of cyclists (Table 2, Paper 5). As discussed in Chapter 8, one possible explanation for the inadequate clearance observed in our studies is that drivers may not be aware of the need to give cyclists 1m clearance when overtaking.

Knowledge of overtaking clearance was further explored in Stage 3. The.majority of respondents reported they provided at least 1m clearance distance when overtaking cyclists (driver-cyclists: 93.3%, drivers: 85.3%). Not surprisingly, drivers who were also cyclists were 2.1 times as likely to report this behaviour as drivers who did not cycle. Females were more likely to provide 1m clearance when overtaking cyclists than males. Other research on overtaking clearance has elucidated contributory characteristics of cyclists, however this study highlights for the first time driver-related factors that influence driver behaviour when overtaking cyclists.

Previous research has highlighted several cyclist-related factors that may contribute to the clearance that drivers provide when overtaking cyclists. Walker (2007) analysed driver overtaking behaviour of cyclists in the UK and reported that male riders wearing a helmet and positioned away from the curb were given the least overtaking space compared to female riders, or riders without a helmet. Based on these observations, Walker proposed a positive association between driver perceived cyclist competence and driver overtaking behaviour: the more competent the rider, the less space drivers are likely to afford them when overtaking. Walker points out the fallibility of such assumptions as passing too closely to a cyclist reduces the margin of error for both the cyclist and the driver (Walker, 2007).

As with any complex road user behaviour, it is likely that the explanation for drivers' overtaking behaviour is multi factorial. In addition to knowledge of safe driving practices, it is possible that cyclists' speed may be a potential confounder in relation to drivers turning in front of cyclists. Drivers may not be fully cognisant of the cyclist's travel speed and as a result, may misjudge the distance required to safely turn ahead of riders. This hypothesis could not be tested in this research as the cyclists' speed was not recorded. While there are techniques available to compute the speed of cyclist from the video footage (Khan & Raksuntorn, 2001), this analysis was beyond the scope of the doctoral study. Further research is needed using methods to record cyclists' speed to determine more precisely the role of cyclists' speed in their interactions with other road users.

The recommendation to provide 1m minimum overtaking distance is outlined in the Victorian driver licence handbook (VicRoads, 2007) and this message has been endorsed in a recent safety campaign by the Amy Gillett Foundation (AGF) called *A Metre Matters* (Amy Gillett Foundation, 2009). A multi-faceted approach has been used in the *A Metre Matters* campaign. The message is promoted at AGF organised rides and is included on AGF cycling jerseys and car bumper stickers. Broad dissemination through media outlets has been achieved with a short video community service announcement that has been aired at cinemas, on several television stations and an audio advertisement on radio stations during peak travel times. In addition, billboards in prominent roadside locations have been used in Melbourne, Sydney and Brisbane since February 2010. However it is clear that awareness of the need to provide 1m clearance does not translate to safe behaviour by all drivers. Further safer driving campaigns are needed, potentially targeting specific driver groups, such as non-cycling drivers, to increase the safety of driver overtaking behaviour.

10.1.1.1 Driver behaviour, knowledge and attitudes

Drivers' behaviour, knowledge and attitudes were the focus of the third study in this doctoral research (Paper 5, Chapter 9). Drivers who are also cyclists were 1.5 times more likely than drivers who were not cyclists to report safe driving behaviour in relation to sharing the road with cyclists. This is perhaps not surprising; drivers who are cyclists are likely to have a better understanding of how driver behaviours affect cyclists and are more likely to interact safely with cyclists when driving. Findings are consistent with previous research that suggests a positive association between cycling participation levels and cyclist safety (Jacobsen, 2003; Pucher & Buehler, 2008b; Elvik, 2009).

This finding should, however, be treated with some caution. Despite higher numbers of cyclists on the road, the prevalence of cyclist serious injuries are still increasing (Henley & Harrison, 2010) suggesting a negative association between cycling participation and cyclist safety. Thus the challenge for cycling in Australia currently is how to adequately provide for the increased number of people cycling without increasing the rate of serious injuries. If a safety in numbers effect is to be achieved in Australia, all of the components of this effect are needed: drivers have an increased expectation and encounters of cyclists on the road; and non-cyclists know someone who is a cyclist; and provision of effective cycling facilities (Jacobsen, 2003; Bonham et al., 2006; Pucher & Buehler, 2008b).

Findings from the road user survey presented in Paper 5 showed that there are significant gaps in drivers' knowledge of cycling related road rules. Only one quarter of all drivers, including those who were also cyclists, were aware of the road rule related to bike lanes which permits drivers to travel in a bike lane for up to 50m to manoeuvre around another vehicle. Only two thirds of drivers were aware that drivers are permitted to enter/cross a dashed bike lane.

These knowledge gaps highlight a potential safety issue for cyclists. As discussed above, behavioural countermeasures offer a potential solution to improve driver knowledge. New drivers can be informed through driver licence handbooks, as well as written and practical driving tests while broader community campaigns may be necessary to inform current drivers of these rules. Further research is needed to determine the relative contribution of these behaviours to cyclist-driver crashes. To achieve this, it is essential that information relevant to cyclists and drivers' use of cycling infrastructure is adequately documented in crash report data. Finally, if drivers' behaviour in relation to non-compliance of cycling-related road rules is indeed a significant contributing factor in cyclist-driver crashes, it is important that these behaviours are managed by legislation, enforcement and supporting educational campaigns. Police cyclist safety programs that include the behaviour of drivers, as well as cyclists, may be a useful strategy for raising awareness of the importance of safe driving behaviours.

The cycling experience of drivers was a significant influence in their attitudes towards cyclists (Paper 5, Chapter 9). Driver-cyclists held the view that most cyclists ride safely (81.0%) and when driving they felt comfortable sharing the road with cyclists regardless of the presence of on-road cycling markings (with lane markings: 91.5%; without lane markings, 71.1%). This finding was consistent with previous research indicating higher prevalence of positive attitudes towards cyclists amongst drivers who are also cyclists (Gatersleben & Appleton, 2007). Conversely, the present study showed that negative attitudes towards cyclists were associated with drivers who do not cycle. When sharing the roads, non-cycling drivers were more likely than their driver counterparts to agree with negative statements about cyclists hold the view that cyclists were unpredictable (drivers: 40.0%, driver-cyclists: 19.1%) and that it was frustrating to repeatedly overtake cyclists (drivers: 30.5%, driver-cyclists: 13.2%).

It is important to determine the impacts of negative attitudes on cyclist safety. However, it should be noted that only a limited number of driving behaviours and attitudes were explored and that there may be other underlying factors not measured here. While we need to understand the relationship between driver negative attitudes towards cyclists and the potential for unsafe driving behaviour, it is also important to reduce drivers' negative attitudes and create a safe, shared road space.

Of particular interest was whether drivers' negative attitudes had any bearing on cyclist safety. Findings from regression modelling presented in Chapter 9 identified significant relationships between respondents' knowledge, attitudes and behaviours. Insufficient use of indicators was associated with respondents who were comfortable sharing the road with cyclists without cycling-related line markings compared to respondents who were not comfortable on roads without this facility. Adequate use of indicators before turning was associated with respondents who were more cautious when sharing the road with cyclists. Head checking before turning left was significantly associated with being comfortable sharing the road without cycling-related line markings. The provision of 1m clearance when overtaking cyclists was associated with knowledge that drivers could enter/cross a dashed bike lane. Intuitively, safety benefits might be gained by improving driver attitudes, particularly relating to cyclists' unpredictability and frustration associated with repeated overtaking.

However, knowledge of safe driving behaviours does not always translate with observed behaviour, as evidenced by drivers' non-compliant behaviour at bike boxes. In the observational study (Publication 2, Chapter 6), half the observed drivers were non-compliant at the bike box, whereas in the survey (Paper 5, Chapter 9), the majority of all respondents were aware of the road rules related to bike boxes. More research is needed to understand whether more specific articulation of rules and greater clarity about rules through other efforts will indeed be effective in improving safe behaviours of drivers.

10.1.2 Cyclist behaviour

Key findings related to cyclist behaviour are derived mainly from the observational studies and include red light running and looking behaviour.

10.1.2.1 Cyclist red light infringement

The findings from the fixed camera observational study (Chapter 5) showed that only a small proportion of all cyclists who faced the red light infringed (6.9%). Interestingly, however, red light infringement was most likely to occur when cyclists were turning left (these cyclists were 28.4 times more likely to infringe than cyclists travelling straight through the intersection). Additional factors influencing red light infringement behaviour were gender and the presence of other road users (see Chapter 5, Table 2). These rates of cyclist infringement confirm previous findings that reported observed cyclist infringement rates at 7-9 per cent of cyclists who faced the red light (Daff & Barton, 2005; Johnson, Charlton & Oxley, 2008).

It was not possible from the observation footage to determine motivations for these factors related to red light infringement. It is possible that cyclists do not perceive turning left to be unsafe, as they did not cross the path of vehicular traffic, travelling either in a forward or cross direction. Males were twice as likely as females to infringe and several authors have proposed that this may be reflective of males propensity for risk taking behaviour, or females propensity for more cautionary and compliant behaviour (Ameratunga et al., 2006; Garrard et al., 2006). Further investigations are needed to determine the characteristics of cyclists who were likely to be influenced by the presence of other road users and why the presence of others has a deterrent effect on their infringement behaviour.

A preliminary analysis of the Stage 3 survey data was conducted to understand cyclists' justifications for red light infringement (see Chapter 9). Findings showed that over a third (37%) of cyclist respondents reported that they had occasionally infringed at signalised intersections. This is more than five times the observed infringement rate in Stage 1. Of the cyclists who reported that they had infringed, the four most common justifications were: turning left (32.9%); their bicycle did not activate the traffic light sensors (30.1%); pedestrian crossing when no pedestrians were waiting or crossing or when cyclists were using the pedestrian crossing (24.4%); and when there was no vehicular traffic (16.1%). More in-depth analysis of these findings was outside the scope of this thesis, however further analysis of cyclist red light infringement behaviour and the role of the road network are planned.

These findings provide useful insights on reasons for red light running behaviour. In light of these findings, it is unlikely that enforcement alone will be effective in reducing cycling red light infringement. A broader, system-wide understanding of what influences this behaviour, including the road network is needed and further research to understand these associations is warranted.

10.1.2.2 Cyclist looking behaviour

The second key finding of this study relating to cyclist behaviour was cyclist looking behaviour. As discussed in Chapter 2, a review of Australian cyclist fatality crashes reported that a contributing factor in one third of crashes was that the cyclist or the driver failed to observe the other road user (Australian Transport Safety Bureau, 2006). While there has been some evidence from studies of *driver* looking behaviour in relation to cyclists, no studies were identified which provided information on *cyclist* looking behaviour in relation to cyclist-driver crashes. To address this gap in knowledge, the Stage 2 naturalistic cycling study was conducted to investigate cyclists' looking behaviour, particularly relating to collision and near-collision events between drivers and cyclists.

Using helmet mounted cameras, cyclists head check behaviour was readily observed from the video footage. Head checks were used as a proxy measure of cyclist looking behaviour. Pre-event, the majority of cyclists (57.3%) made right-ward head checks, while fewer cyclists head checked to their left (37.1%). The finding of fewer left-ward head checks is not unexpected because cyclists travel curbside, and typically there are no other road users to their left. Cyclists appeared to have a much higher situational awareness than drivers, and this is not surprising given their vulnerability and positioning on the road (see Chapter 8, Table 2).

Further, it was evident that cyclists reacted to the movement of the traffic around them. This, it is assumed that by engaging in this avoidance behaviour that the likelihood of a crash event is lessened. Pre-event, the majority of cyclists were observed to be riding in a safe and legal manner (see Chapter 8, Table 2). Again, these are interesting findings and warrant further analysis to investigate the role of cyclists' defensive and anticipatory riding style in avoiding cyclist-driver crashes.

In the two collisions observed in the naturalistic cycling study it appeared that the *cyclists did not see the vehicle*. The riders did not head check towards the vehicle involved in the collision. This is an important point. Thus, while it appeared that many potential crashes were avoided because cyclists were highly engaged in their environment - they watch and anticipate driver behaviour – collisions were associated with an apparent lapse in the cyclist's vigilance and failure to look in the direction of the vehicle. This finding is consistent with conclusions of previous studies of Australian cyclist-driver crashes (Australian Transport Safety Bureau, 2006), indicating that both cyclist and driver failure to see the other road user was a contributing factor. This finding also highlights the need for cyclists and drivers to be more alert when travelling on the road and for a road network that is designed to accommodate a cyclist error such as failure to see (Swedish Road Administration, 2006).

Further, it is possible that some cyclists may also be contributing to some collisions or near-collisions by positioning themselves in the driver's blind spot, particularly when sharing the road with larger commercial vehicles or 4WD vehicles. In the UK, Transport for London has addressed the issue of cyclist safety and blind spots in relation to lorries, or heavy goods vehicles (Transport for London, 2010). The campaign included an online video that showed the perspective of the driver and the cyclist at midblock locations and when turning, as well as images depicting the blind spots for the driver of a heavy goods vehicle. To date, there have been no evaluations of the campaign to demonstrate its effectiveness in changing behaviour or reducing cyclist-heavy vehicle collisions. While the blind spots for private vehicles and smaller commercial vehicles are considerably less than those affecting the drivers of heavy vehicles, the positioning of cyclists may contribute to events involving drivers' left turn looked-but-failed-to-see behaviour. Increased driver awareness of blind spots is likely to be important to cyclist safety. Similarly, education for cyclists about the safest positions on the road in relation to adjacent vehicles and avoiding the drivers' blind spot may have positive safety outcomes for on-road cyclists in Australia.

Overall, findings from this research have provided important new information on cyclists' looking behaviour that suggests that cyclists may be more aware of the road environment compared with drivers and more vigilant than had previously been reported. It is important that both drivers and cyclists actively look for each other on the road. Training from both the driver and cyclist perspective about head checking and positioning on the road may have positive safety outcomes for cyclists.

10.1.3 A safe system for all road users

In this doctoral research, the focus has been on the safety of cyclists, in particular how they interact with drivers on the road. Understanding the impact of the dynamic relationship between the two groups is a critical and consistent theme underpinning the research. It is essential that road safety initiatives and polices are developed with consideration of the target road user group(s) and the impact these policies may have on other groups. Arguably, greater attention is needed on the safety of road users who are not protected by a vehicle. In the current Australian context, the inclusion of 'vulnerable' road users in the SSF needs to be more explicit to ensure that road safety campaigns consider and include unprotected road users, cyclists and pedestrians. In Figure 10-2, 'road users' has been expanded to identify all four road user groups, the diagram illustrates that there is an interaction between all groups.

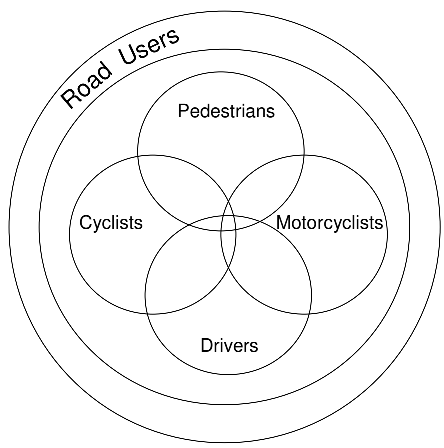

Figure 10-2 Inclusive road users model

The primary aim of the current road safety policy in Victoria is to reduce overall road trauma by 30 per cent and reductions of cyclist trauma contribute to this aim. To accurately monitor the progress towards this aim for cyclists, it is essential that crash data is calculated using accurate exposure data.

10.1.3.1 Monitoring cyclist safety

Data – exposure

The primary aim of the current road safety policy in Victoria is to reduce road trauma by 30 per cent by the year 2017 (VicRoads, 2008b). To accurately monitor the progress towards this aim for cyclists, it is essential that crash data is calculated using accurate exposure data.

Currently in Australia, little is known about the details of cyclist trips and this precludes meaningful analysis of cyclist crash statistics. Accurate cyclist exposure data is fundamental to: determine crash rates per distance travelled, time travelled or per population of cyclists; and to evaluate the effectiveness of new initiatives including on-road cycling facilities. In Europe, cyclist travel diaries have been a key component in understanding cyclist behaviour and participation rates, and providing meaningful denominator data in the estimation of crash risk. Similarly, it will be important to develop an accurate, long-term surveillance protocol in Australia, to advance our understanding of cycling participation rates and cyclist crash risk.

Data – crash statistics

Major gaps exist in the current status of knowledge about cyclist crashes due to insufficient reporting of data and underreporting of crashes. As discussed in Chapter 1, Section 1.2.3, current cyclist crash data in Australia is limited by severe underreporting (Ameratunga et al., 2006; Harman, 2007) errors and bias (Langley et al., 2006) and definition inconsistencies across jurisdictions (Watson & Cameron, 2006). Meaningful interpretation of the crash data are further hampered by a lack of representative cycling participation data (Sikic et al., 2009).

Broader education messages may be useful to raise awareness of cyclists and drivers about the importance of reporting cyclist crashes. Additionally, changes are needed in official reporting of cyclist crashes to ensure pertinent details are recorded. For example, the pre-event behaviour of driver and cyclists including looking behaviour, swerving or braking may provide critical information pertinent to crash causation.

10.2 Safer roads

While the findings discussed thus far suggest that the behaviours of cyclists and drivers are a key component in determining the safety of on-road cyclists, this study also provides evidence that driver behaviour and cyclist safety is influenced by the road environment that they travel on.

In this section, the role of roads and the influence of cycling facilities and road design on cyclist safety are discussed. In Stage 1, observations at intersections provided information on behaviour at different types of cycling facilities. In Stage 2, the naturalistic cycling study, findings highlighted the role of cycling facilities in cyclist-driver collision or near-collision. In Stage 3, driver-cyclists' and non-cycling drivers' understanding of road rules related to cycling facilities (bike lane and bike boxes) were examined and the influence of knowledge on safe driving behaviours was considered.

10.2.1 On-road cycling facilities

The intended purpose of cycling facilities is to create a safe space on the road for cyclists. Specifically, the intent of these facilities is to provide cyclists and drivers with 'a clear understanding of what is expected of them and from each other' (VicRoads, 1999). However, findings from observational studies in Stage 1 and Stage 2 showed that half of observed driver were non-compliant at bike boxes at intersections, suggesting a lack of clarity about the intent of these facilities. The behaviour of cyclists and driver at on-road cycling facilities and drivers' understanding of rules related to cycling facilities are discussed below.

10.2.1.1 At intersections – bike box

At first glance, bike boxes are a sound and practical safety solution, affording a safe space for cyclists to wait ahead of waiting vehicular traffic (Daff & Barton, 2005). However, the findings from this research showed a level of non-compliance amongst both drivers and cyclists in relation to bike boxes, potentially compromising the safety of cyclists.

Drivers were frequently observed to breach the bike box space, regardless of the position of the bike box in relation to vehicular lanes. Drivers were less compliant than cyclists when the bike box was positioned in front of the left vehicular lane (drivers: 49.8%, cyclists: 64.9%) or the centre lane (drivers: 49.8%, cyclists: 64.9%) (see Chapter 6, Table 1). Poor knowledge of the rules was proposed as a possible explanation for the low driver compliance. However, results from the survey showed that the majority of respondents were aware of the rules relating to keeping the bike box clear, even when turning left. Interestingly, cycling experience influenced driver knowledge: drivers who were also cyclists were over 2 times more likely to be aware of these rules than drivers who did not cycle (see Chapter 9, Table 3).

How survey respondents learned about the bike box rules was not explored in the survey so it could not be determined if knowledge was due to formal driver education or practical driver training; self-education or because the purpose of the bike box was intuitively obvious. Nevertheless, the noted discrepancy between the low observed driver compliance at bike boxes and the high level of knowledge of the road rules needs to be understood better in order to improve compliance at these facilities. Further, greater enforcement of non-compliant drivers at bike boxes may be needed to ensure the facility does provide a safe space for cyclists on the road.

While compliance is a reasonable measurement of the effectiveness of the bike box in creating a safe space for cyclists, there is an implicit assumption that bike boxes are an effective safety design solution. Currently, the bike box design used in Australia is not connected to the midblock bike lane (see Figure 1, Publication 2). This design leaves cyclists without a designated passage to transition from the bike lane to the bike box. Importantly, there are no clear line markings or information about road user priority at the section of road where the most complicated cyclist-driver manoeuvre must occur; that is, where drivers turn left across the path of cyclists.

In jurisdictions outside Australia, the bike lane and bike box are typically connected with a continuous bike lane, or with painted bike symbols indicating a space for cyclists. Figure 10-3 shows one solution used in Europe, with painted bike symbols to clearly indicate cyclists' access to the bike box where there is not sufficient space for a standard bike lane. In Portland, Oregon in the US, connected bike lane/bike boxes are increasingly installed at intersections. At some locations, both the bike lane and bike box are painted green, and some have instructions to drivers to 'Wait Here'. Drivers and cyclists reported higher levels of comfort and safety at the intersections following installation of a connected bike box compared with pre-installation levels of comfort and safety (Dill, Monsere & McNeil, In Press, Corrected Proof).

Figure 10-3 Symbols to bike box, Brussels, Belgium

Cycling facilities have been largely retrofitted in Australia, with most facilities being fitted into spaces that were previously allocated to vehicles. At locations where new infrastructure has been implemented, it is important that adequate *in situ* signage is installed to ensure the purpose of the facility is understood.

Another consideration in the effectiveness of bike box infrastructure in Australia is the emphasis placed on education. Cycling facilities are only briefly referred to in the current Victorian driver licence handbook, under 'Special purpose lanes' and do not explicitly detail or provide an illustration of the range of bike box facilities (VicRoads, 2010). It is essential that details of cycling facilities are included in the handbook with additional questions incorporated in the written test and the on-road driving test for licensure.

In addition to informing new drivers about the road rules related to cycling facilities, it is important that the education messages reach all drivers. In Victoria, in November 2009, numerous changes were made to the road rules across a wide range of laws including bike boxes, namely increased penalties for non-compliant drivers. This information was provided to the public on the VicRoads website, while this initiative is encouraging, the animation was only used on the webpage for cyclists and is no longer available. The webpage for drivers did not include the animation, with just a written explanation of behaviour at bike boxes. It is not known how many drivers (or cyclists) accessed the site to learn about these facilities and if any changes in behaviour may have occurred.

In addition to the safety implications of compliance and knowledge about bike box rules discussed above, the effectiveness of these facilities may also be influenced by other behaviours. Bike boxes encourage cyclists to roll through to the front of waiting traffic and while there are positive benefits to cyclists taking this position, there are also some unintended consequences. This behaviour was evident in the observational studies of cyclists reported in Chapter 8. Leapfrogging, or the practice of cyclists and drivers repeatedly overtaking each other between midblock and intersection was also observed in Stage 2 observations: typically, the driver overtakes the cyclist in the midblock section of road; the cyclist overtakes the driver at the intersection in order to take up their position in the bike box; and, subsequently, the driver overtakes the same cyclists in the next midblock section. In this sense, the bike boxes may be inadvertently contributing to a culture of competition, rather than co-operation on the road between cyclists and drivers (Jonasson, 1999). The survey findings revealed that over one third of drivers (39.1%) reported it was frustrating to repeatedly overtake cyclists (compared to 13.9% of cyclists) (see Chapter 9, Table 2).

Behaviour at bike boxes was also found to be related to the positioning of the bike box. As described in Figure 1 in Publication 2, these facilities may be located in front of the left or centre vehicular lane. Findings from the Stage 1 observational study showed that some cyclists, particularly women, did not use the bike box. It is possible that cyclists perceived this position would make them more vulnerable since they would be positioned in front of vehicles that were continuing straight. Instead, cyclists were observed to line up in single file alongside the waiting vehicle rather than roll forward. This was especially obvious at the centre bike box, as shown in Figure 10-4. This behaviour has the potential to increase collision risk for cyclists.

Figure 10-4 Cyclists single file formation instead of bike box

At these 'centre' lane locations, a single file bike 'lane' next to the vehicular lane may be a preferred option rather than a bike box. This type of facility would not place cyclists in competition with drivers for space and may increase driver compliance and subsequently, improve cyclist safety.

Further there are some dangerous anomalies in the positioning of some bike boxes at intersections in Melbourne. At some intersections along major commuter routes, the bike box is located in front of the left-most lane. This creates a potential risk for cyclists because the lane also has a left turn filter light that permits drivers to turn left while those travelling forward must comply with a red light (see Figure 10-5).

Figure 10-5 Approach to bike box in Melbourne

Similarly, cyclists using this facility may turn with the left turn arrow or wait in the bike box if travelling straight ahead, thus creating an obstacle to drivers and potentially contributing to disharmony between cyclists and drivers. In the Stage 1 observations, drivers were frequently seen to turn left and drive through the intersection, forcing the cyclists into the gutter to avoid the turning car. A comprehensive evaluation of the effectiveness of cycling facilities at intersections is needed to examine the impact of different types of facilities on safety and traffic flow. Safer alternatives need to be developed at sites with ambiguous or contradictory facilities.

While cycling facilities need to be effective, functional, intuitive and safe for cyclists and other road users, there is also a need to ensure drivers comply with the cycling facilities. Given the high level of knowledge about the bike box facility, yet low driver compliance, police enforcement of non-compliant drivers may be an effective solution to increase driver compliance and to ensure the space is kept clear for cyclists. Intuitively, greater enforcement of driver compliance with cycling infrastructure should also raise drivers' awareness that they are a key component in cyclist safety.

10.2.1.2 Intersection cycling facilities – continuous bike lane

The continuous bike lane facility provides a continuous, parallel lane designated for cyclist use. Cyclists wait, often in single file within the space during the red light phase. Cyclists' behaviour at intersections with continuous bike lanes was investigated in the Stage 1, observational study in this doctoral research.

High driver (97.7%) and cyclist (95.4%) compliance was observed at the continuous bike lane sites (see Chapter 6, Table 1). A comparison of compliance at the continuous bike lane sites compared to the bike box sites showed that cyclists were 12.4 times more likely to be compliant (see Chapter 6, Table 2) and drivers were 43.8 times more likely to be compliant (see Chapter 6, Table 3). Closer inspection of the data showed reduced leapfrogging behaviour which, arguably, may lead to lower driver frustration and reduced competition between drivers and cyclists for space on the road. Road design with a mismatch of cycling facilities that gives priority to cyclists on some road sections and discontinues at other sections along the same route, is likely to contribute to on-road confusion. A review of on-road cycling facilities is recommended to evaluate the effectiveness of the facilities for cyclist safety, traffic flow and driver behaviour.

Currently in Melbourne, implementation of continuous bike lanes at intersections is not widespread and the efficacy of these facilities needs to be better understood. Given the high compliance rates observed among cyclists and drivers, this infrastructure appears to offer a positive alternative to disconnected cycling facilities. It is proposed that a review of reported cyclist-vehicle crashes before and after the installation of the continuous bike lane at selected sites would be a useful approach to quantify the effectiveness of the continuous bike lane on cyclist safety.

Currently, in Australia, a range of different stakeholders and local government areas are targeting specific locations independently, however, there is currently no macro-level planning for integrated and connected cycling in Melbourne or in Australia. Given the recent increases in cycling participation, Australia is well poised to trial different on-road cycling facilities. As the number of cyclists continues to increase in cities and regional areas, test sites could be established to trial and evaluate models of cycling facilities such as connected bike lanes and bike boxes that have demonstrable safety benefits, internationally (Dill et al., In Press, Corrected Proof). In addition, it will be important to develop new and innovative approaches that take into account unique aspects of the Australian road environment

In sum, there is a need for greater understanding of the role of the road network in how drivers and cyclists interact in a range of different locations and whether and how the existing cycling facilities are effective. Cycling needs to be included in all urban planning and it is important to refine facilities to continue to improve cyclist safety. Currently, standard police and hospital crash reports make no provision for recording details about the cycling facilities at crash sites. To enable accurate monitoring and future investigation of different on-road facilities, it is essential that these details are recorded when crashes occur and notations are made if behaviour related to the cycling facility was deemed to be a contributing factor.

Further, crash data can be used to inform where cycling facilities are implemented, which types are effective and what needs to be improved. Recording the details of the road environment is an important link in the injury causation chain. Comprehensive cycling-inclusive details are critical to ensure accurate environmental factors are included in analyses that may result in preventing future crashes.

10.3 Limitations of the doctoral research

Limitations of this doctoral research were identified in Chapters 4 through 9. The main issues are summarised below.

In total, 10 sites and three cycling-specific infrastructure settings were studied from the fixed camera observations, yielding over 90 hours of data for 2,670 cyclists and 1,243 vehicles. Notwithstanding the considerable insights gained from this rich data source, there were limitations to the number and types of intersections that could be observed as the observations were supervised by the researcher and manual data analysis methods were resource intensive. The observations were conducted in metropolitan areas at peak travel times and the findings may not be applicable to cyclists at non-metropolitan locations, at other times of the day or on weekends. It was outside the scope of a doctoral project in terms of time and budget, to explore a broader range of intersection types and collect a larger and potentially more representative sample of video footage for each intersection type. It will be important that additional studies are conducted to capture cyclist and driver behaviour at other times of day, in other seasons and with different types of intersections and cycling facilities in order to provide a comprehensive analysis of the relevant behavioural characteristics and other factors that impact on the safety of cyclists. Improved video analysis technology had the potential to expedite and ideally automate data reduction in the future.

In Stage 2, the naturalistic study, participant bias is likely to have been a limiting factor in generalisability of the findings. While the observations provided more than 120 hours of commuter cyclist trips, the sample size was relatively small. The participants were all experienced, confident riders who were familiar with the routes that were observed. It may be that the findings cannot be generalised to riders with less experience, or to experienced riders in less familiar locations. Further research is needed to explore situation awareness levels of less experienced cyclists and the implications for their safety.

As with Stage 1, data reduction and analysis of the video footage required an intensive process and was therefore limited to the available resources and timeframe for a PhD. Additional analyses are planned to further explore cyclists' experiences across the entire commuter trip.

There were also limitations in the technology used in Stage 2. The cameras had poor low light sensitivity and this restricted the times of day that could be recorded. More recently, compact video camera technology has improved and many of the technological limitations, including recording in low light conditions have been overcome. Another technology-related limitation in Stage 2 was a lack of accurate measurement of the cyclists' speed. Again the technology has improved since the Stage 2 study was conducted and cameras are now available with built-in or plug-in GPS to accurately record speed in future studies.

Recruitment methods for the Stage 3 survey also present a potential source of sampling bias. The Amy Gillett Foundation (AGF) was involved in the survey recruitment, by advertising the link to the survey on their website and social network page. The activities of the AGF are focused on promotion of cycling safety and their interest extends to a scholarship supporting this doctoral research. It is possible that respondents who were recruited through the AGF had a greater awareness of some of the issues investigated, such as providing a metre when overtaking and this may limit the generalisability of the findings. It was not possible to ascertain how many respondents had an affiliation with the AGF or other recruitment sources. While participants recruited through the AGF may have had a more positive safety ethos, efforts were made to reduce such biases by recruiting from a number of other sources including Monash University and online cyclist forums where cycling participation is likely to be promoted more prominently than safety.

10.4 Conclusions

The overall aim of this doctoral research was to identify characteristics of the road users and road system that contribute to cyclist crash risk. Three research stages were undertaken using novel observational methods and survey based approaches. Important findings were presented on cyclist and driver behaviours and characteristics that place cyclists at risk and potential solutions were highlighted to improve cyclist safety.

Drivers were shown to have a significant role in on-road cyclist safety and are a greater contributing factor in unsafe cyclist-driver interactions than has been previously reported. The most important driver behaviour associated with unsafe cyclist-driver events was driver left turn across the path of cyclists and included inadequate signal time before turning, lack of head check and insufficient clearance when overtaking cyclists. Improvements in safe driving behaviours are needed to increase cyclist safety.

Significant gaps were identified in drivers' knowledge related to the road rules for bike lanes. Positive attitudes towards cyclist were more frequently associated with drivers who were also cyclists, while negative attitudes towards cyclists were more likely to be held by non-cyclists. Greater education and awareness efforts are needed to improve road users' knowledge of cycling-related road rules and the safety implications for cyclists of unsafe driving behaviours.

Observations of behaviour at intersections showed that a proportion of cyclists infringe at red lights. Encouragingly, observed rates were significantly lower than self-reported infringements. Predictive factors for red light infringement included direction of travel (left turn) and gender (male). The presence of other road users (cross traffic and in the same direction) had a deterrent effect. Further research is needed to determine the safety implications of cyclist red light infringement.

Cyclists were observed making frequent head checks and were highly aware of the environment around them. Notwithstanding this high level of vigilance, cyclists' failure to see a vehicle may be a contributing factor for crashes. Notably, in the two collisions observed in the naturalistic cycling study there was an absence of head checking by cyclists prior to the crash. In contrast, all near-collision events were characterised by cyclist head checking and in the majority of these events, there was no driver avoidance response observed, suggesting that the vehicle driver was at fault. Greater driver awareness of cyclists is needed to ensure cyclists' failure to see does not result in a cyclist-driver crash.

Despite sound knowledge of several of the road rules relating to cycling facilities, the observed rate of driver compliance at bike boxes was less than 50 per cent. Thus, while there are likely to be benefits gained from increased awareness about cycling infrastructure laws, the findings of this research highlight that behaviour is not necessarily tightly coupled with knowledge. Solutions are needed to ensure roads are more bicycle inclusive with facilities that clearly allocate space on the road for both cyclists and drivers so that their intent is more intuitive to the user.

Cycling participation is increasing in Australia and represents an expanding portion of commuter traffic. A significant challenge for road traffic policy managers will be to meet the associated demands of this changing mix of road users while providing a safe environment for all. It is critical that road safety initiatives accommodate the vulnerable cyclist population. To effect this, broad safe system principles should be the basis for policy development and initiatives.

Chapter 11

Bibliography

ABC News. (2007). Melbourne's 'hell ride' a recipe for disaster, says coroner. Retrieved 7 June, 2010, from http://www.abc.net.au/news/stories/2007/07/26/1989114.htm

Åberg, L., & Rimmo, P.-A. (1998). Dimensions of aberrant driver behaviour. *Ergonomics, 41*(1), 39-56.

Access Economics. (2009). *The economic cost of spinal cord injury and traumatic brain injury in Australia* from http://www.vni.com.au/sitebuilder/about/knowledge/asset/files/99/final_vni_report_2010_july_6.pdf

Adler, P., & Adler, P. (1998). Observational Techniques. In N. K. Denzin & Y. S. Lincoln (Eds.), *Collecting and Interpreting Qualiative Methods*. Thousand Oaks, California: Sage.

Aertsens, J., de Geus, B., Vandenbulcke, G., Degraeuwe, B., Broekx, S., De Nocker, L., et al. (2010). Commuting by bike in Belgium, the costs of minor accidents. *Accident Analysis & Prevention, 42*(6), 2149-2157.

Allen, D., Bygrave, S., & Harper, H. (2005). *Behaviour at cycle advanced stop lines*: Transport Research Laboratory.

Ameratunga, S., Hijar, M., & Norton, R. (2006). Road-traffic injuries: confronting disparities to address a global-health problem. *The Lancet, 367*(9521), 1533-1540.

Amy Gillett Foundation. (2009). *A metre ma*tters. http://www.amygillett.org.au/a-metre-matters Viewed 26 March 2010

Archer, J. (2005). *Indicators for traffic safety assessment and prediction and their application in micro-simulation modelling: A study of urban and suburban intersections.* Stockholm, Sweden.

Archer, J. (2008). *Conflict Observation Study at Melbourne Metropolitan Intersection: Fitzroy Street and Lakeside Drive*. Clayton: Monash University Accident Research Centre.

Arnberger, A., Haider, W., & Brandenberg, C. (2005). Evaluating Visitor-Monitoring Techniques: A Comparison of Counting and Video Observation Data. *Environmental Management, 36*(2), 317-327.
Atkinson, J. E., & Hurst, P. M. (1983). Collisions between cyclists and motorists in New Zealand. *Accident Analysis & Prevention, 15*(2), 137-151.
Atkinson, R., & Flint, J. (2001). Accessing Hidden and Hard-To-Reach Populations: Snowball Research Strategies. *Social Research Update*(33).
Attewell, R. G., Glase, K., & McFadden, M. (2001). Bicycle helmet efficacy: a meta-analysis. *Accident Analysis and Prevention, 33*(3), 345-352.
Aultman-Hall, L., & Hall, F. L. (1998). Ottawa-Carleton commuter cyclist on-and off-road incident rates. *Accident Analysis and Prevention, 30*(1), 29-43.
Australian Transport Council. (2009). *Australian Road Rules*. Canberra: National Road Transport Commission.
Australian Transport Safety Bureau. (2006). *Deaths of cyclists due to road crashes*: Australian Government.
Australian Transport Safety Bureau. (2008). *Road crash casualties and rates, Australia, 1925 to 2005*. Retrieved 16 February 2011, from http://www.infrastructure.gov.au/roads/safety/publications/2008/pdf/1925_05_casualties.pdf
Austroads. (1999). *Guide to Traffic Engineering Practice: Bicycles. Part 14*. Sydney.
Austroads. (2005). *The Australian National Cycling Strategy 2005-2010*. Sydney.
Bacchieri, G., Barros, A. J. D., dos Santos, J. V., & Gigante, D. P. (2010). Cycling to work in Brazil: Users profile, risk behaviors, and traffic accident occurrence. *Accident Analysis & Prevention, 42*(4), 1025-1030.
Ballham, A., Absoud, E. M., Kotecha, M. B., & Bodiwala, G. G. (1985). A study of bicycle accidents. *Injury, 16*(6), 405-408.
Barnett, D. J., Balicer, R. D., Blodgett, D., Fews, A. L., Parker, C. L., & Links, J. M. (2005). The Application of the Haddon Maxtrix to Public Health Readiness and Response Planning. *Environmental Health Perspectives, 113*(5), 561-566.
Basford, L., Reid, S., Lester, T., Thomson, J., & Tolmie, A. (2002). *Drivers' perceptions of cyclists*: Department for Transport.
Bell, D., & Kuranami, C. (1994). Nonmotorized vehicles in Phnom Penh: existing situations and options for improvement. *Transportation Research Board*(1441), 93-100.
Bhatia, R., & Wier, M. (2011). "Safety in Numbers" re-examined: Can we make valid or practical inferences from available evidence? *Accident Analysis & Prevention, 43*(1), 235-240.
Bibby, P. (2009, 16 January 2009). Suburban cyclists 'racing without road rules'. *The Age*.
Bicycle Network. (2010). *The Annual Super Tuesday Bike Count: National Executive Summary 2010*.
Bicycle Victoria. (2009). *National Ride to Work Day 2008, Follow-up survey report*. Melbourne.
Black. (1994). Why we need qualitative research.
Bonham, J., Cathcart, S., Petkov, J., & Lumb, P. (2006). *Safety in Numbers: A Strategy for Cycling?* Paper presented at the 29th Australasian Transport Research Forum
Bostrom, L., & Nilsson, B. (2001). A Review of Serious Injuries and Deaths from Bicycle Accidents in Sweden from 1987 to 1994. *Journal of Trauma-Injury Infection & Critical Care, 50*(5), 900-907.
Brown, K., & Spinney, J. (2010). Catching a Glimpse: The Value of Video in Evoking, Understanding and Representing the Practice of Cycling. In B. Fincham, M. McGuinness & L. Murray (Eds.), *Mobile Methodologies*. Hampshire: Palgrave Macmillan.
Brown, K. M., Dilley, R., & Marshall, K. (2008). Using a Head-Mounted Video Camera to Understand Social Worlds and Experiences. *Sociological Research Online, 13 (6) 1*(http://www.socresonline.org.uk/13/6/1.html).
Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative Research, 6*(1), 97-113.
Bull, J. P. (1975). The injury severity score of road traffic casualties in relation to mortality, time of death, hospital treatment time and disability. *Accident Analysis and Prevention, 7*(4), 249-255.

Bull, J. P., & Roberts, B. J. (1973). Road accident statistics--A comparison of police and hospital information. *Accident Analysis and Prevention, 5*(1), 45-53.

Bureau of Infrastructure Transport and Regional Economics. (2006). *Road crash costs in Australia, 2006*. Canberra.

Bureau of Infrastructure Transport and Regional Economics. (2010). *Road Deaths Australia: 2009 Statistical Summary*. Canberra.

Cameron, M., Helman, L., & Neiger, D. (1992). *Evaluation of the Bicycle Helmet Wearing Laws in Victoria During Its First 12 Months* (No. 32). Clayton: Monash University Accident Research Centre.

Cameron, M. H., Finch, C. F., & Vulcan, A. P. (1994). *The Protective Performance of Bicycle Helmets Introduced at the Same Time as the Bicycle Helmet Wearing Law in Victoria*. Clayton: Monash University Accident Research Centre.

Carr, D., Skalova, M., & Cameron, M. H. (1995). *Evaluation of the Bicycle Helmet Wearing Law in Victoria During its First Four Years*. Clayton: Monash University Accident Research Centre.

Carter, D., Hunter, W., Zegeer, C., Stewart, J. R., & Huang, H. H. (2007). Bicyclist Intersection Safety Index. *Transport Research Record, 2031*, 18-24.

Cassell, E. P., Finch, C. F., & Stathakis, V. Z. (2003). Epidemiology of medically treated sport and active recreation injuries in the Latrobe Valley, Victoria, Australia. *British Journal of Sports Medicine, 37*(5), 405-409.

Chapman, R. (1973). The concept of exposure. *Accident Analysis & Prevention, 5*(2), 95-110.

Chong, S., Poulos, R., Olivier, J., Watson, W. L., & Grzebieta, R. (2010). Relative injury severity among vulnerable non-motorised road users: Comparative analysis of injury arising from bicycle-motor vehicle and bicycle-pedestrian collisions. *Accident Analysis & Prevention, 42*(1), 290-296.

City of Melbourne. (2004). Issue paper: Cycling. *www.melbourne.vic.gov.au/rsrc/PDFs/MelbourneTransportStrategy/MelbTS_Cycling1407.rtf*.

City of Melbourne. (2007). *Melbourne Bicycle Account - Cycling Census 2007*.

City of Melbourne. (2008). *Melbourne Bicycle Account - Cycling Census 2008*. Melbourne: City of Melbourne.

Conche, F., & Tight, M. (2006). Use of CCTV to determine road accident factors in urban areas. *Accident Analysis & Prevention, 38*(6), 1197-1207.

Corben, B., Logan, D. B., & Oxley, J. (2008). *Star rating school walking routes* (No. 275). Clayton: Monash University Accident Research Centre.

Couper, M. P. (2008). *Designing effective web surveys*. New York: Cambridge University Press.

Crundall, D., Bibby, P., Clarke, D., Ward, P., & Bartle, C. (2008). Car drivers' attitudes towards motorcyclists: A survey. *Accident Analysis & Prevention, 40*(3), 983-993.

Cupples, J., & Ridley, E. (2008). Towards a heterogeneous environmental responsibility: sustainability and cycling fundamentalism. *Area, 40*(2), 254-264.

Cycling Promotion Fund. (2009). *Bicycle Sales 2008*. Viewed on 17 September 2009.

Daff, M., & Barton, T. (2005). *Marking Melbourne's Arterial Roads to Assist Cyclists*. Paper presented at the ITE 2005 Annual Meeting and Exhibit. Institute of Transportation Engineers.

Davies, D., Halliday, M., Mayes, M., & Pocock, R. (1997). *Attitudes to cycling: a qualitative study and conceptual framework*: Transport Research Laboratory.

de Lapparent, M. (2005). Individual cyclists' probability distributions of severe/fatal crashes in large french urban areas. *Accident Analysis & Prevention, 37*(6), 1086-1092.

Dennerlein, J. T., & Meeker, J. D. (2002). Occupational Injuries Amongst Boston Bicycle Messengers. *American Journal of Industrial Medicine, 42*, 519-525.

Department of Communications Information Technology and the Arts. (2009). *Participation in Exercise, Recreation and Sport Annual Report 2008*. Retrieved. from.

Department of Communications Information Technology and the Arts. (2010). *Participation in Exercise, Recreation and Sport Annual Report 2009*. Retrieved. from.

Department of Infrastructure. (2002). *Melbourne 2030: Planning for sustainable growth*. Retrieved. from.

Department of Infrastructure, T., Regional Development and Local Government,. (2010). *Road Deaths Australia: 2009 Statistical Summary*. Canberra.

Department of the Environment, W., Heritage and the Arts. (2010). *National Strategy for Ecologically Sustainable Development*. Retrieved. from.

Depreitere, B., Van Lierde, C., Maene, S., Plets, C., Vander Sloten, J., Van Audekercke, R., et al. (2004). Bicycle-related head injury: a study of 86 cases. *Accident Analysis & Prevention, 36*(4), 561-567.

Dholakia, N., & Sinha, P. K. (2005). Observations on Observation in India's Dynamic Ubran Markets. *Qualitative Social Research, 6*(1).

Dill, J. (2009). Bicycling for Transportation and Health: The Role of Infrastructure. *Journal of Public Health, 30*, S95-S110.

Dill, J. (2010). *2010 Ogden Transport Lecture: 'Towards sustainable urban mobility: insights from Portland's journey'*.

Dill, J., & Carr, T. (2003). Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them. *Transportation Research Record, 1828*, 116-123.

Dill, J., Monsere, C. M., & McNeil, N. (In Press, Corrected Proof). Evaluation of bike boxes at signalized intersections. *Accident Analysis & Prevention*.

Dill, J., & Voros, K. (2007). Factors Affecting Bicycling Demand: Initial Survey Findings from Portland, Orgeon, Region. *Journal of the Transportation Research Board, 2031*, 9-17.

Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., et al. (2006). *The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment*. Virginia: Virginia Tech Transportation Institute.

Dominiczak, P. (2010, 9 March 2010). Cyclists could be allowed to pass through red lights in bid to cut road deaths. *London Evening Standard*.

Eddleston, M., Buckley, N. A., Gunnell, D., Dawson, A. H., & Konradsen, F. (2006). Identification of strategies to prevent death after pesticide self-poisoning using a Haddon matrix. *Injury Prevention, 12*(5), 333-337.

Eilert-Petersson, E., & Schelp, L. (1997). An epidemiological study of bicycle-related injuries. *Accident Analysis & Prevention, 29*(3), 363-372.

Ekman, R., & Welander, G. (1998). The results of 10 years of experience with the Skaraborg bicycle helmet program in Sweden. *International Journal of Injury Control and Safety Promotion, 5*(1), 23-39.

Elvik, R. (2009). The non-linearity of risk and the promotion of environmentally sustainable transport. *Accident Analysis & Prevention, 41*(4), 849-855.

Farris, C., Spaite, D. W., Criss, E. A., Valenzuela, T. D., & Meislin, H. W. (1997). Observational Evaluation of Compliance With Traffic Regulations Among Helmeted and Nonhelmeted Bicyclists. *Annals of Emergency Medicine, 29*(5), 625-629.

Federal Chamber of Automotive Industries. (2010). SUV Sales Drive New Car Market Higher in Australia. *Accessed on 14 September 2010, at http://www.fcai.com.au/news/all/all/249/suv-sales-drive-new-car-market-higher-in-august*.

Fedtke, J. (2003). Strict Liability for Car Drivers in Accidents Involving "Bicycle Guerrillas"? Some Commonets on the Proposed Fifth Motor Directive of the European Commission. *The American Journal of Comparative Law, 51*(4), 941-957.

Ferguson, J. (2006). Bike bullies ignore law. In. Melbourne: News Corporation Limited.

Ferrándiz, F., & Baer, A. (2008). Digital Memory: The Visual Recording of Mass Grave Exhumations in Contemporary Spain. *Forum: Qualitative Social Research, 9*(3).

Finch, C., Cameron, M. H., Vulcan, A. P., Finch, C. F., & Newstead, S. V. (1994). Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia--An evaluation. *Accident Analysis and Prevention, 26*(3), 325-337.

Finch, C., Heiman, L., & Neigher, D. (1993). *Bicycle use and helmet wearing rates in Melbourne, 1987 to 1992: the influence of the helmet wearing law*. Clayton: Monash University Accident Research Centre.

Finch, C., Valuri, G., & Ozanne-Smith, J. (1998). Sport and active recreation injuries in Australia: evidence from emergency department presentations. *Br J Sports Med, 32*(3), 220-225.

Fincham, B. (2006). Bicycle messengers and the road to freedom. *The Editorial Board of the Sociological Review*, 209-222.

Friede, A. M., Azzara, C. V., Gallagher, S. S., & Guyer, B. (1985). The epidemiology of injuries to bicycle riders. *Pediatr Clin North Am, 32*(1), 141-151.

Garrard, J. (2009). Active transport: Adults, An overview of recent evidence. Retrieved 25 June, 2010, from http://www.goforyourlife.vic.gov.au/hav/articles.nsf/practitioners/active_transport?Open

Garrard, J., Crawford, S., & Hakman, N. (2006). *Revolutions for Women: Increasing women's participation in cycling for recreation and transport*. Burwood: Deakin University.

Garrard, J., Greaves, S., & Ellison, A. (2010). Cycling injuries in Australia: Road safety's blind spot? *Journal of the Australasian College of Road Safety, 21*(3).

Garrard, J., Rose, G., & Lo, S. K. (2008). Promoting transportation cycling for women: The role of bicycle infrastructure. *Preventive Medicine, 46*, 55-59.

Gatersleben, B., & Appleton, K. M. (2007). Contemplating cycling to work: Attitudes and perceptions in different stages of change. *Transportation Research Part A: Policy and Practice, 41*(4), 302-312.

Gavin, A., Meuleners, L., Cercarekkum, K., & Hendrie, D. (2005). An Overview of Bicycle Crashes and Injuries in Western Australia. *Journal of the Australian College of Road Safety, July*.

Gold, R. L. (1958). Roles in Sociological Field Observations. *Social Forces, 36*(3), 217-223.

Gomm, R. (2004). *Social Research Methodology*. London: Palgrave Macmillan.

Google. (2010). Google maps. Retrieved 13 October, 2010, from http://maps.google.com.au/maps?hl=en&tab=wl

Gordon, J. E. (1949). The Epidemiology of Accidents. *America Journal of Public Heath, 39*, 504-515.

Green, F. K. (2003). *Red light running*. Vermont South.

Guarnieri, M. (1992). Landmarks in the history of safety. *Journal of Safety Research, 23*(3), 151-158.

Haddon, W. (1963). A note concerning accident theory and research with special reference to motor vehicle accidents. *Annals of the New York Academy of Sciences, 107*(Research Metholodogy and Potential in Community Health and Preventive Medicine), 636-646.

Haddon, W. (1970). On the escape of tigers: an ecologic note. *America Journal of Public Heath and the Nation's Health, 60*(12), 2229-2234.

Haddon, W. (1972). A logical framework for categorizing highway safety phenomena and activity. *Journal of Trauma, 13*, 321-331.

Haileyesus, T., Annest, J. L., & Dellinger, A. M. (2007). Cyclists injured while sharing the road with motor vehicles. *Inj Prev, 13*(3), 202-206.

Harkey, D. L., & Carter, D. L. (2006). Observational Analysis of Pedestrian, Bicyclist, and Motorist Behaviors at Roundabouts in the United States. *Journal of the Transportation Research Board*, 155-165.

Harkey, D. L., & Stewart, J. R. (1997). Evaluation of shared-use facilities for bicycles and motor vehicles. *Transportation Research Record*(1578).

Harman, B. (2007). *Bicycle Safety and Law Enforcement*. Paper presented at the Australasian Road Safety Research Policing and Education Conference.

Harris, S. (1990). The real number of road traffic accident casualities in the Netherlands: a year-long survey. *Accident Analysis and Prevention, 22*(4), 371-378.

Harrison, D. (2007, 2 May 2007). Hell ride cyclist under pressure from pack. *The Age*.

Hatfield, J., Murphy, S., Job, R. F. S., & Du, W. (2009). The effectiveness of audio-tactile lane-marking in reducing various types of crash: A review of evidence, template for evaluation, and preliminary findings from Australia. *Accident Analysis & Prevention, 41*(3), 365-379.

Heng, K. W. J., Lee, A. H. P., Zhu, S., Tham, K. Y., & Seow, E. (2006). Helmet use and bicycle-related trauma in patients presenting to an acute hospital in Singapore. *Singapore Med J, 47*(5), 367-372.

Henley, G., & Harrison, J. E. (2009). *Serious injury due to land transport accidents, Australia, 2006-07*. Australian Government: Australian Institute of Health and Welfare,.

Henley, G., & Harrison, J. E. (2010). *Serious injury due to land transport accidents, Australia, 2006-07*. Australian Government: Australian Institute of Health and Welfare,.

Herbert Martinez, K. L., & Porter, B. E. (2006). Characterizing red light runners following implementation of a photo enforcement program. *Accident Analysis & Prevention, 38*(5), 862-870.

Herrstedt, L. (1992). Traffic calming design - a speed management method. *Accident Analysis and Prevention, 24*(1), 3-16.

Herslund, M.-B., & Jørgensen, N. O. (2003). Looked-but-failed-to-see-errors in traffic. *Accident Analysis & Prevention, 35*(6), 885-891.

Holtslag, H. R., van Beeck, E. F., Lichtveld, R. A., Leenen, L. P., Lindeman, E., & van der Werken, C. (2008). Individual and population burdens of major trauma in the Netherlands. *Bulletin of the World Health Organisation, 86*, 111-117.

Hook, W., & Replogle, M. (1996). Motorization and non-motorized transport in Asia. *Land Use Policy, 13*(1), 69-84.

Hoque, M. (1990). An analysis of fatal bicycle accidents in Victoria (Australia) with a special reference to nighttime accidents. *Accident Analysis and Prevention, 22*(1), 3-11.

Howe, K. R. (1988). Against the Quantitative-Qualitative Incompatibility Thesis or Dogmas Die Hard. *Educational Researcher, 17*(8), 10-16.

Hunter, W. W. (2000). *Evaluation of a Combined Bicycle Lane/Right Turn Lane in Eugene, Oregon*: University of North Carolina, Chapel Hill, Federal Highway Administration.

Hunter, W. W., Stewart, J. R., Stutts, J., Huang, H. H., & Pein, W. E. (1999). *A comparative analysis of bicycle lanes versus wide curb lanes: final report*. Chapel Hill, NC: University of North Carolina.

Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Inj Prev, 9*(3), 205-209.

Javouhey, E., Guerin, A.-C., & Chiron, M. (2006). Incidence and risk factors of severe traumatic brain injury resulting from road accidents: A population-based study. *accident Analysis and Prevention, 38*, 225-233.

Johnson, M., Charlton, J., & Oxley, J. (2008). *Cyclists and red lights - a study of the behaviour of commuter cyclist in Melbourne.* Paper presented at the Australasian Road Safety Research, Policing and Education Conference, Adelaide, 10-12 November.

Johnson, M., Oxley, J., & Cameron, M. (2009). *Cyclist bunch riding: a review of the literature*. Clayton: Monash University Accident Research Centre.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher, 33*(7), 14-26.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research, 1*(2), 112-133.

Jonasson, M. (1999). The ritual of courtesy -- creating complex or uneqivocal places? *Transport Policy, 6*(1), 47-55.

Joshi, M. S., Senior, V., & Smith, G. P. (2001). A diary study of the risk perceptions of road users. *Health, Risk & Society, 3*(3), 261-279.

Karkhaneh, M., Kalenga, J. C., Hagel, B. E., & Rowe, B. H. (2006). Effectiveness of bicycle helmet legislation to increase helmet use: a systematic review. *Injury Prevention, 12*(2), 76-82.

Khan, S. I., & Raksuntorn, W. (2001). Accuracy of Numerical Rectifications of Video Images to Analyze Bicycle Traffic Scenes. *Transport Research Record*(1773), 32-38.

Kim, J.-K., Kim, S., Ulfarsson, G., F, & Porrello, L., A. (2007). Bicyclist injury severities in bicycle-motor vehicle accidents. *Accident Analysis and Prevention, 39*(2), 238-251.

Klauer, S. G., Neale, V. L., Dingus, T. A., Ramsey, D., & Sudweeks, J. (2005). Driver Inattention: A Contributing Factor to Crashes and Near-Crashes. *Human Factors and Ergonomics Society Annual Meeting Proceedings, Surface Transportation*, 1922-1926.

Koustanaï, A., Boloix, E., Van Elslande, P., & Bastien, C. (2008). Statistical analysis of "looked-but-failed-to-see" accidents: Highlighting the involvement of two distinct mechanisms. *Accident Analysis & Prevention, 40*(2), 461-469.

Kroll, B., & Ramey, M. R. (1977). Effects of Bike Lanes on Driver and Bicyclist Behavior. *Transportation Engineering Journal.*

Lahausse, J. A., van Nes, N., Fildes, B. N., & Keall, M. D. (2010). Attitudes towards current and lowered speed limits in Australia. *Accident Analysis & Prevention, 42*(6), 2108-2116.

Langford, J. (2005). Australasia's Safe System Approach to Road Safety.

Langley, J., Stephenson, S., Thorpe, C., & Davie, G. (2006). Accuracy of injury coding under ICD-9 for New Zealand public hospital discharges. *Injury Prevention, 12:*, 58-61.

Larsson, P., Dekker, S. W. A., & Tingvall, C. (2010). The need for a systems theory approach to road safety. *Safety Science, 48*, 1167-1174.

Lawson, S. D. (1991). *Red-light running: accidents and surveillance cameras*. Birmingham: AA Foundation for Road Safety Research and Birmingham City Council.
Leveson, N. G. (2011). Applying systems thinking to analyze and learn from events. *Safety Science, 49*, 55-64.
Liller, K. D. (2000). The importance of obstetricians/ gynecologists in promoting children's unintentional injury prevention: a focus on bicycle helmet use. *Prim Care Update Ob Gyns, 7*(2), 60-63.
Lindqvist, K. S. (1991). Epidemiology of traffic accidents in a Swedish municipality. *Accident Analysis and Prevention, 23*(6), 509-519.
Loo, B. P. Y., & Tsui, K. L. (2007). Factors affecting the likelihood of reporting road crashes resulting in medical treatment to the police. *Inj Prev, 13*(3), 186-189.
Loo, B. P. Y., & Tsui, K. L. (2010). Bicycle crash casualties in a highly motorized city. *Accident Analysis & Prevention, In Press, Corrected Proof*.
Lujic, S., Finch, C., Boufous, S., Hayen, A., & Dunsmuir, W. (2008). How comparable are road traffic crash cases in hospital admissins data and police records? An examinatino of data linkage rates. *Australian and New Zealand Journal of Public Health, 32*(1).
Macpherson, A., & Spinks, A. (2007). Bicycle helmet legislation for the uptake of helmet use and prevention of head injuries (Review). *Cochrane Database of Systematic Reviews*(2).
Marais, K., Dulac, N., & Leveson, N. G. (2004). *Beyond Normal Accidents and High Reliability Organizations: The Need for an Alternative Approach to Safety in Complex Systems*. Paper presented at the Engineering Systems Division Symposium.
Matthews, M. L., & Boothby, R. D. (1980). *Visibility of Cyclists at Night: Laboratory Evaluation of Three Rear Warning Devices*: Guelph University.
Maycock, G., Brocklebank, P., & Hall, R. (2003). Road layout design standards and driver behaviour. *Transport, 156*(2), 115-122.
Mayou, R., & Bryant, B. (2003). Consequences of road traffic accidents for different types of road user. *Injury International Journal of the Care of the Injured, 34*, 197-202.
McCarthy, M., & Gilbert, K. (1996). Cyclist road deaths in London 1985-1992: drivers, vehicles, manoeuvres and injuries. *Accident Analysis and Prevention, 28*(2), 275-279.
McClintock, H., & Cleary, J. (1996). Cycle facilities and cyclists' safety : Experience from Greater Nottingham and lessons for future cycling provision. *Transport Policy, 3*(1-2), 67-77.
McGuire, L., & Smith, N. (2000). Cycling safety: injury prevention in Oxford cyclists. *Inj Prev, 6*(4), 285-287.
McNaughton, M. J. (2009). Closing in on the Picture: Analyzing Interactions in Video Recordings. *International Journal of Qualitative Methods, 8*(4).
Medew, J. (2007, 27 July 2007). Coroner slams aggressive Hell Riders. *The Age*.
Mohan, D. (2002). Road safety in less-motorized environments: future concerns. *Int. J. Epidemiol., 31*(3), 527-532.
Moritz, W. E. (1997). Innovative Bicycle Treatments: An Informational Report. *Transportation Research Record, 1578*.
Nankervis, M. (1999). The effect of weather and climate on bicycle commuting. *Transportation Research Part A: Policy and Practice, 33*(6), 417-431.
National Coroners Information System. (2006). Fatal Facts: Case study 2 - Bicycle accidents. *July, Edition 10*.
National Road Safety Council. (2010). Road Safety Fact Sheet NRSC2, Safe System Approach.
Neale, V. L., Dingus, T. A., Klauer, S. G., Sudweeks, J., & Goodman, M. (2005). *An overview of the 100-car naturalistic study and findings*. Paper presented at the 19th International Technical Conference on Enhanced Safety of Vehicles.
Neale, V. L., Klauer, S. G., Knipling, R. R., Dingus, T. A., Holbrook, G. T., & Petersen, A. (2002). *The 100 Car Naturalistic Driving Study, Phase 1 - Experimental Design*. Blacksburg, Virginia: Virginia Tech Transportation Institute.
New South Wales Government. (2010). *NSW BikePlan*.
Newman, A. (2002). *The marking of advanced cycle lanes and advanced stop boxes at signalised intersections*. Christchurch.
Newstead, S. V., Cameron, M. H., Gantzer, S., & Finch, C. F. (1994). *Bicyclist head injuries in Victoria three years after the introduction of mandatory helmet use*. Clayton: Monash University Accident Research Centre.
Noyes, J. (1998). *Managing errors*. Paper presented at the UKACC International Conference on CONTROL.

O'Connor, J. P., & Brown, T. D. (2007). Real Cyclists Don't Race: Informal Affiliations of the Weekend Warrior. *International Review for the Sociology of Sport, 42*(1), 83-97.
Oakes, D. (2007, 11 July 2007). Hell Riders to feel police presence in the heavens. *The Age*.
Olkkonen, S., Lahdenranta, U., Slatis, P., & Honkanen, R. (1993). Bicycle accidents often cause disability--an analysis of medical and social consequences of nonfatal bicycle accidents. *Scand J Soc Med, 21*(2), 98-106.
Osberg, J. S., Stiles, S. C., & Asare, O. K. (1998). Bicycle safety behavior in Paris and Boston. *Accident Analysis & Prevention, 30*(5), 679-687.
Öström, M., Bjornstig, U., Naslund, K., & Eriksson, A. (1993). Pedal cycling fatalities in northern Sweden. *Int J Epidemiol, 22*(3), 483-488.
Paterson, B. L., Bottorff, J. L., & Hewat, R. (2003). Blending Observational Methods: Possibilities, Strategies and Challenges. *International Journal of Qualitative Methods, 2*(1).
Peterson, L., Brazeal, T., Oliver, K., & Bull, C. (1997). Gender and Developmental Patterns of Affect, Belief, and Behavior in Simulated Injury Events. *Journal of Applied Developmental Psychology, 18*, 531-546.
Petty, R. (1998). The Impact of the Sport of Bicycle Riding on Safety Law. *American Business Law Journal, Winter 98, Vol 35*(2), 185.
Pijnenburg, B., & Van Duin, M. (1990). The Zeebrugge ferry disaster. *Contemporary Crises, 14*, 321-349.
Porter, B. E., & Berry, T. D. (2001). A nationwide survey of self-reported red light running: measuring prevalence, predictors, and perceived consequences. *Accident Analysis & Prevention, 33*(6), 735-741.
Porter, B. E., & England, K. J. (2000). Predicting Red-Light Running Behavior: A Traffic Safety Study in Three Urban Settings. *Journal of Safety Research, 31*(1), 1-8.
Pucher, J., & Buehler, R. (2008a). *Cycling for Everyone: Lessons from Europe*: Transportation Research Board.
Pucher, J., & Buehler, R. (2008b). Making Cycling Irresistible: Lessons from the Netherlands, Denmark, and Germany. *Transport Reviews, 28*.
Pucher, J., & Dijkstra, L. (2003). Promoting Safe Walking and Cycling to Improve Public Health: Lessons From The Netherlands and Germany. *Am J Public Health, 93*(9), 1509-1516.
Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine, 50*(Supplement 1), S106-S125.
Pucher, J., Komanoff, C., & Schimek, P. (1999). Bicycling renaissance in North America? Recent trends and alternative policies to promote bicycling. *Transportation Research Part A, 33*, 625-654.
Räsänen, M., Koivisto, I., & Summala, H. (1999). Car Driver and Bicyclist Behavior at Bicycle Crossings Under Different Priority Regulations. *Journal of Safety Research, 30*(1), 67-77.
Räsänen, M., & Summala, H. (1998). Attention and expectation problems in bicycle-car collisions: an in-depth study. *Accident Analysis & Prevention, 30*(5), 657-666.
Räsänen, M., & Summala, H. (2000). Car Drivers' Adjustments to Cyclists at Roundabouts. *Transportation Human Factors, 2*(1), 1-17.
Rasmussen, E. S. (1982). Human error: a taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents, 4*, 311-333.
Rasmussen, J. (1997). Risk management in a dynamic society: a modelling problem.
Reason, J. (1990). *Human error: models and management*.
Reason, J. (2000). Human error: models and management. *BMJ, 320*(7237), 768-770.
Rennie, R. (2009, 11 May 2009). Road safety blitz in Melbourne's CBD. *The Age*.
Retting, R. A., Ulmer, R. G., & Williams, A. F. (1999). Prevalence and characteristics of red light running crashes in the United States. *Accident Analysis & Prevention, 31*(6), 687-694.
Retting, R. A., & Williams, A. F. (1996). Characteristics of red light violators: Results of a field investigation. *Journal of Safety Research, 27*(1), 9-15.
Richter, M., Otte, D., Haasper, C., Knobloch, K., Probst, C., Westhoff, J., et al. (2007). The current injury situation of bicyclists--a medical and technical crash analysis. *The Journal of Trauma, Injury, Infection and Critical Care, 62*(5), 1118-1122.

Richter, M., Pape, H.-C., Otte, D., & Krettek, C. (2005). Improvements in passive car safety led to decreased injury severity - a comparison between the 1970s and 1990s. *Injury International Journal of the Care of the Injured, 36*, 484-488.

Rivara, F. P., Thompson, D. C., & Thompson, R. S. (1997). Epidemiology of bicycle injuries and risk factors for serious injury. *Inj Prev, 3*(2), 110-114.

Robinson, D. L. (2005). Safety in numbers in Australia: more walkers and bicyclists, safe walking and bicycling. *Health Promotion Journal of Australia, 16*(1), 47-51.

Robinson, D. L. (2006). Do enforced bicycle helmet laws improve public health? *BMJ, 332*(7543), 722-.

Rodgers, G. B. (1995). Bicyclist deaths and fatality risk patterns. *Accident Analysis and Prevention, 27*(2), 215-223.

Romano, E., Tippetts, S., & Voas, R. (2005). Fatal red light crashes: the role of race and ethnicity. *Accident Analysis & Prevention, 37*(3), 453-460.

Rosenkranz, K. M., & Sheridan, R. L. (2003). Trauma to adult bicyclists: a growing problem in the urban environment. *Injury International Journal of the Care of the Injured, 34*, 825-829.

Rosenstein, B. (2002). Video Use in Social Science Research and Program Evaluation. *International Journal of Qualitative Methods, 1*(3).

Rowe, B. H., Rowe, A. M., & Bota, G. W. (1995). Bicyclist and environmental factors associated with fatal bicycle-related trauma in Ontario. *Cmaj, 152*(1), 45-53.

Runyan, C. W. (1998). Using the Haddon matrix: introducing the third dimension. *Injury Prevention, 4*(4), 302-307.

Runyan, C. W. (2003). Introduction: Back to the Future ”Revisiting Haddon's Conceptualization of Injury Epidemiology and Prevention. *Epidemiologic Reviews, 25*(1), 60-64.

Runyan, C. W., & Runyan, D. K. (1991). How Can Physicians Get Kids to Wear Bicycle Helmets? A Prototypic Challenge in Injury Prevention. *American Journal of Public Health,* pp. 972-973.

Sandin, J. (2009). An analysis of common patterns in aggregated causation charts from intersection crashes. *Accident Analysis & Prevention, 41*(3), 624-632.

Schlep, L., & Ekman, R. (1990). Road Traffic Accidents in a Swedish Muncipality. *Public Health, 104*, 55-64.

Schramm, A., Rakotonirainy, A., & Haworth, N. (2008). *How much does disregard of road rules contribute to bicycle-vehicle collisions?* Paper presented at the National Conference of the Australasian College of Road Safety and Travelsafe Committee of the Queensland Parliament, Brisbane.

Sikic, M., Mikocka-Walus, A., Gabbe, B. J., McDermott, F. T., & Cameron, P. A. (2009). Bicycle injuries and mortality in Victoria, 2001-2006. *Medical Journal of Australia, 190*, 353-356.

Silkstone, D., & Burrow, V. (2006). Fast, furious, fatal: official eye falls on Hell Ride. *The Age*.

Silverman, D. (2001). *Interpreting Qualitative Data*. London: Sage Publications.

Skelly, R. (1995). The wrong way to riches. *Alberta Report / Newsmagazine, 22*(50), 25.

Slack, F., & Rowley, J. (2000). Observation: Perspectives on Research Methodologies for Leisure Managers. *Management Research News, 23*.

Smith, P., Waterman, M., & Ward, N. (2006). Driving aggression in forensic and non-forensic populations: Relationships to self-reported levels of aggression, anger and impulsivity. *British Journal of Psychology, 97*, 387-403.

Smith, T. W. (2001). *Are representative internet surveys possible?* Paper presented at the Statistics Canada Symposium

Standing Committee on Health and Ageing. (2009). *Weighing it up: Obesity in Australia*. Retrieved. from.

Stewart, K., & Williams, M. (2005). Researching online populations: the use of online focus groups for social research. *Qualitative Research, 5*, 395-416.

Stone, M., & Broughton, J. (2003). Getting off your bike: cycling accidents in Great Britain in 1990-1999. *Accident Analysis and Prevention, 35*(4), 549-556.

Summala, H. (1988). Risk control is not risk adjustment: the zero-risk theory of driver behaviour and its implications. *Ergonomics, 31*(4), 491-506.

Summala, H., Pasanen, E., Räsänen, M., & Sievanen, J. (1996). Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis & Prevention, 28*(2), 147-153.

Summala, H., & Räsänen, M. (2000). Top-Down and Bottom-Up Processes in Driver Behavior at Roundabouts and Crossroads. *Transportation Human Factors, 2*(1), 29-37.
Swedish Road Administration. (2006). *Safe traffic: Vision Zero on the move*.
SWOV Institute for Road Safety Research. (2009). SWOV Fact sheet: Mobility on Dutch roads. *http://www.swov.nl/rapport/Factsheets/UK/FS_Mobility.pdf, Viewed 5 July 2010*.
Telfer, B., & Rissel, C. (2003). *Cycling to work in Sydney: journey-to-wrok Census datea from 1996 to 2001*.
Thompson, D. C., Rivara, F. P., & Thompson, R. (2009). Helmets for preventing head and facial injuries in bicyclists (Review). *Cochrane Database of Systematic Reviews*(4).
Tingvall, C. (1998). *The Swedish 'Vision Zero' and how parliamentary approval was obtained*. Paper presented at the Key note address at the National Road Safety Research, Policing and Education Conference, Wellington, New Zealand.
Tingvall, C., & Haworth, N. (1999). *Vision Zero - An ethical approach to safety and mobility*. Paper presented at the 6th ITE International Conference Road Safety and Traffic Enforcement: Beyond 2000.
Transport for London. (2010). Cycle safety/Cycling near lorries. Retrieved 15 June 2010, from http://www.tfl.gov.uk/roadusers/cycling/14799.aspx
Turner, S., Wood, G., Luo, Q., Singh, R., & Allatt, T. (2010). Crash prediction models and the factors that influence cycle safety. *Journal of the Australasian College of Road Safety, August 2010*.
van der Horst, R. (1990). *A time-based analysis of road user behaviour at intersection*. Paper presented at the 3rd ICTCT workshop.
van Haeften, M. (2010). Het kijkgedrag van automobilisten en fietsers bij kruispunten met een tweerichtingsfietspad (Viewing behaviour of drivers and cyclists at intersections with a two-way cycle track), University of Groningen, Groningen. In J. P. Schepers (Ed.). (Cited in: Road factors and bicycle-motor vehicle crashes at unsignalized priority intersections. Accid. Anal. Prev. (2010), doi:10.1016/j.aap.2010.11.005).
Van Loon, A. (2001). *Sustainable Safety: A Successful Road Safety Program in The Netherlands.* . Paper presented at the XII Canadian Multidisciplinary Road Safety Conference.
van Teijlingen, E. R., & Hundley, V. (2001). The importance of pilot studies. *Social Research Update*(35).
Viano, D., von Holst, H., & Gordon, E. (1997). Serious brain injury from traffic-related causes: Priorities for primary prevention. *Accident Analysis and Prevention, 29*(6), 811-816.
VicRoads. (1999). *Cycle Notes. No. 2. Bicycle lanes* (No. 01404).
VicRoads. (2000). *Cycle Notes. No. 5. "Head Start" Storage Areas At Intersections* (No. 01404).
VicRoads. (2001). Cycle Notes No. 9 - Creating On-Road Space for Cyclists.
VicRoads. (2004). *Cycling to work in Melbourne, 1976-2001* (No. 01356). Melbourne.
VicRoads. (2005). *Cycle Notes. No. 14. Coloured Surface Treatments for Bicycle Lanes* (No. 01404).
VicRoads. (2007). *Road to Solo Driving: learning to drive, driving to learn*. Kew, Victoria: Roads Corporation Victoria.
VicRoads. (2008a). New congestion plan to ease peak pressure. (Accessed 15.5.09). Retrieved 13 May 2009
VicRoads. (2008b). *Victoria's Road Safety Strategy: Arrive Alive 2008-2017*. Melbourne.
VicRoads. (2010). *Road to Solo Driving: learning to drive, driving to learn*. Kew, Victoria: Roads Corporation Victoria.
Road Safety Act 1986. Version No. 115, (1999).
Vis, A. A., Dijkstra, A., & Slop, M. (1992). Safety effects of 30 km/h zones in the Netherlands. *Accident Analysis & Prevention, 24*(1), 75-86.
Wachtel, A., & Lewiston, D. (1994). Risk Factors for Bicycle-Motor Vehicle Collisions at Intersections. *ITE Journal, September*, 30-35.
Walker, I. (2005). Signals are informative but slow down responses when drivers meet bicyclists at road junctions. *Accident Analysis & Prevention, 37*(6), 1074-1085.
Walker, I. (2007). Drivers overtaking bicyclists: objective data on the effects of riding position, helmet use, vehicle type and apparent gender. *Accident Analysis and Prevention, 39*(2), 417-425.
Wall, G., Davies, D., & Crabtree, M. (2003). *Capacity implications of Advanced Stop Lines for cyclists*. TRL Report TRL 585.

Wang, S. Y., Wang, S. F., & Chi, G. B. (1997). Epidemiological features and determinants of road injury in China. *Zhonghua Liu Xing Bing Xue Za Zhi, 18*(3), 134-137.
Wasserman, S., & Faust, K. (1995). *Social network analysis: methods and applications*: Cambridge University Press.
Watson, L., & Cameron, M. (2006). *Bicycle and motor vehicle crash characteristics*: Research Report 251. Monash University Accident Research Centre. Melbourne.
Wegman, F., Aarts, L., & Bax, C. (2008). Advancing sustainable safety: National road safety outlook for The Netherlands for 2005-2020. *Safety Science, 46*(2), 323-343.
Welander, G., Ekman, R., Svanstrom, L., Schelp, L., & Karlsson, A. (1999). Bicycle injuries in Western Sweden: a comparison between counties. *Accident Analysis and Prevention, 31*(1-2), 13-19.
Wesemann, P., Norden, Y. v., & Stipdonk, H. (2010). An outlook on Dutch road safety in 2020; future developments of exposure, crashes and policy. *Safety Science, 48*(9), 1098-1105.
Wong, E., Leong, M. K. F., Anantharaman, V., Raman, L., Wee, K. P., & Chao, T. C. (2002). Road traffic accident mortality in Singapore. *The Journal of Emergency Medicine, 22*(2), 139-146.
World Health Organisation. (2006). *Helmets: A road safety manual for decision-makers and practitioners*.
World Health Organisation. (2009). *Global status report on road safety: Time for action*. Geneva.
Wright, L., & Montezuma, R. (2004). *Reclaiming public space: the economic, environmental and social impacts of Bogotá's transformation*. Paper presented at the Walk 21-V Cities for People, The Fifth International Conference on Walking in the 21st Century.
Yan-Hong, L., Rahim, Y., Wei, L., Gui-Xiang, S., Yan, Y., De Ding, Z., et al. (2006). Pattern of traffic injuries in Shanghai: implications for control. *International Journal of Injury Control and Safety Promotion, 13*(4), 217 - 225.
Zentner, J., Franken, H., & Lobbecke, G. (1998). Head injuries from bicycle accidents. *Clinical Neurology and Neurosurgery, 98*, 281-285.

Chapter 12

Appendices

Appendix 12.1
Ethics approval certificate – Observational study

MONASH University

Standing Committee on Ethics in Research Involving Humans (SCERH)
Research Office

Human Ethics Certificate of Approval

Date	**2 January 2008**
Project Number	**CF07/4949 - 2007002122**
Project Title	**Observations of cyclists and other road users**
Chief Investigator	**Dr Judith Charlton**
Approved	**From: 2 January 2008 To: 2 January 2013**

Terms of approval

1. Approval is only valid whilst you hold a position at Monash University.
2. It is the responsibility of the Chief Investigator to ensure that all pending information (such as permission letters from organisations) is forwarded to SCERH. Research cannot begin at an organisation until SCERH receives a permission letter from that organisation.
3. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by SCERH.
4. You should notify SCERH immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash University letterhead and the Monash University complaints clause must contain your project number.
6. **Amendments to the approved project:** Requires the submission of a Request for Amendment form to SCERH and must not begin without written approval from SCERH. Substantial variations may require a new application.
7. **Future correspondence:** Please quote the project number and project title above in any further correspondence.
8. **Annual reports:** Continued approval of this project is dependent on the submission of an Annual Report. This is determined by the date of your letter of approval.
9. **Final report:** A Final Report should be provided at the conclusion of the project. SCERH should be notified if the project is discontinued before the expected date of completion.
10. **Monitoring:** Projects may be subject to an audit or any other form of monitoring by SCERH at any time.
11. **Retention and storage of data:** The Chief Investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.

[redacted]

Dr Souheir Houssami
Executive Officer, Human Research Ethics (on behalf of SCERH)

Cc: Ms Jennifer Anne Oxley; Ms Marilyn Johnson

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Appendix 12.2
Ethics approval certificate – Naturalistic cycling study

MONASH University

Standing Committee on Ethics in Research Involving Humans (SCERH)
Research Office

Human Ethics Certificate of Approval

Date:	**10 December 2008**
Project Number:	**CF08/3275 - 2008001601**
Project Title:	**Naturalistic study of commuter cyclists in metropolitan Melbourne**
Chief Investigator:	**Dr Judith Charlton**
Approved:	**From: 10 December 2008 to 10 December 2013**

Terms of approval

1. The Chief investigator is responsible for ensuring that permission letters are obtained and a copy forwarded to SCERH before any data collection can occur at the specified organisation. **Failure to provide permission letters to SCERH before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research.**
2. Approval is only valid whilst you hold a position at Monash University.
3. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by SCERH.
4. You should notify SCERH immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash University letterhead and the Monash University complaints clause must contain your project number.
6. **Amendments to the approved project (including changes in personnel):** Requires the submission of a Request for Amendment form to SCERH and must not begin without written approval from SCERH. Substantial variations may require a new application.
7. **Future correspondence:** Please quote the project number and project title above in any further correspondence.
8. **Annual reports:** Continued approval of this project is dependent on the submission of an Annual Report. This is determined by the date of your letter of approval.
9. **Final report:** A Final Report should be provided at the conclusion of the project. SCERH should be notified if the project is discontinued before the expected date of completion.
10. **Monitoring:** Projects may be subject to an audit or any other form of monitoring by SCERH at any time.
11. **Retention and storage of data:** The Chief Investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.

[redacted]

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Appendix 12.3
Ethics approval certificate – Online survey

MONASH University

Standing Committee on Ethics in Research Involving Humans (SCERH)
Research Office

Human Ethics Certificate of Approval

Date:	**24 March 2009**
Project Number:	**CF09/0751 - 2009000329**
Project Title:	**An investigation into experiences and attitudes of on-road cycling**
Chief Investigator:	**Dr Judith Charlton**
Approved:	**From: 24 March 2009 To: 24 March 2014**

Terms of approval

1. The Chief investigator is responsible for ensuring that permission letters are obtained and a copy forwarded to SCERH before any data collection can occur at the specified organisation. **Failure to provide permission letters to SCERH before data collection commences is in breach of the National Statement on Ethical Conduct in Human Research and the Australian Code for the Responsible Conduct of Research.**
2. Approval is only valid whilst you hold a position at Monash University.
3. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by SCERH.
4. You should notify SCERH immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash University letterhead and the Monash University complaints clause must contain your project number.
6. **Amendments to the approved project (including changes in personnel):** Requires the submission of a Request for Amendment form to SCERH and must not begin without written approval from SCERH. Substantial variations may require a new application.
7. **Future correspondence:** Please quote the project number and project title above in any further correspondence.
8. **Annual reports:** Continued approval of this project is dependent on the submission of an Annual Report. This is determined by the date of your letter of approval.
9. **Final report:** A Final Report should be provided at the conclusion of the project. SCERH should be notified if the project is discontinued before the expected date of completion.
10. **Monitoring:** Projects may be subject to an audit or any other form of monitoring by SCERH at any time.
11. **Retention and storage of data:** The Chief Investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.

[redacted]

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Appendix 12.4
Online survey

The grey shaded banner(s) on each page indicates a new web page for the online survey.

Cycling safety survey

1. Welcome

Thank you for your interest in this cycling safety research.

The aim of this study is to identify ways to improve safety for on-road cyclists by understanding the experiences of cyclists and drivers. It is anticipated that the responses will contribute to identifying the specific areas that need to be targeted to improve cyclist safety.

This survey is part of a PhD research project conducted by Marilyn Johnson with Dr Judith Charlton and Dr Jennie Oxley at the Monash University Accident Research Centre (MUARC).

The research is being funded through a joint scholarship with Monash University Accident Research Foundation and the Amy Gillett Foundation's Safe Family Research scholarship provided by Bradley and Bayly.

*** 1. You need to be over 18 years of age to answer this survey. Please confirm you are over 18 years of age by clicking the tick box below.**

○ Yes, I confirm that I am over 18 years of age

2. Explanatory Statement

Your consent
Please read through this Explanatory Statement carefully. Ensure that you have read and understood the statement fully before you start.

Background and purpose of the research
Cycling is Australia's fourth most popular physical activity and the number of people cycling continues to increase, however, also increasing is the number of cyclists involved in collisions. There has been limited research into cyclist experiences in Australia that includes the behaviours of cyclists and their interaction with other road users.

The aim of this study is to identify ways to improve safety for on-road cyclists. It is anticipated that the responses collected will provide new and valuable insights into the experiences of cyclists and drivers on the road and what specific areas need to be targeted to improve cyclist safety.

Benefits of the study
The possible benefits of this study will be to identify specific factors that can be addressed to improve safety for on-road cyclists. It is unlikely that there will be any direct benefits to you personally during your participation.

Your participation
In this survey you will be asked about your experiences, behaviour and attitudes on cycling in Australia. Your involvement in this research requires you to fill in this online survey only.

It should take you approximately 20-25 minutes to complete the survey. If you feel uncomfortable answering any questions, feel free to leave that question blank. If you experience distress in relation to your participation in the study while responding to the survey, please contact the researcher (details on the next page).

Confidentiality

Cycling safety survey

All responses will be kept confidential and only the researchers named above will have access to the study data. The responses will be kept by the researchers in password protected electronic files for at least 5 years according to university policy. In publications of the results, all information will be presented in groups and no individual will be identifiable.

At the end of the survey you will be asked if you are interested in participating in future research. If you are interested, you will be asked to provide your name and contact details; however these details will not be linked to your survey responses.

Your contact details will be kept confidential under the Monash University privacy policy and you will only be contacted under the circumstances that you have given permission.

Voluntary participation
Your participation in this research is entirely voluntary and you are free to stop answering questions at any time, your responses will not be recorded until you press 'Done' at the end of the survey. Once your survey has been submitted it is not possible to withdraw, as your survey is anonymous and the researchers will not be able to identify individual responses. No payment will be provided to any participant for their involvement in this study.

Study results
A summary of the findings of the study will be available to participants. This summary will provide the main findings of the study. If you would like a summary please indicate this at the end of the survey.

The ethical aspects of this research project have been approved by the Monash University Human Research Ethics Committee.

*** 2. I agree that I have read and understood the Explanatory Statement.**

○ Yes

3. Contact details

If you would like to contact the researchers about any aspect of this study, please contact the Chief Investigator:

Dr Judith Charlton
Monash University Accident Research Centre
Building 70, Clayton campus
Monash University Vic 3800
Tel: + 61 3 9905 4371
Fax: + 61 3 9905 4363
Email: Judith.Charlton@muarc.monash.edu.au

If you have a complaint concerning the manner in which this research is being conducted (CF09/0751-2009000329), please contact:

Executive Officer
Monash University Human Research Ethics Committee
Building 3e, Room 111, Research Office
Monash University Vic 3800
Tel: + 61 3 9905 2052
Fax: + 61 3 9905 1420
Email: muhrec@adm.monash.edu.au

4. Driving

The questions in this section relate to your experiences while driving.

Page 2

Cycling safety survey

3. Do you currently have a driver's licence (full or probationary)?

- ◯ Yes
- ◯ No

5. Driving experience

4. What type of vehicle licence(s) do you hold?

- ☐ Car
- ☐ Motorcycle
- ☐ Truck
- ☐ Bus

Other (please specify)

5. How many years have you held a car licence? (years with a full licence, not including learner's permit or probationary licence)

6. On average, how many kilometres do you drive (a car) per week?

- ◯ Less than 100 km
- ◯ 101-200 km
- ◯ 201-500 km
- ◯ over 501 km

7. Who does most of the driving in your household?

- ◯ Yourself
- ◯ Partner
- ◯ Other (please specify)

Cycling safety survey

8. In the last 2 years when driving have you incurred any of the following traffic infringements? (please respond to each item using the boxes on the right)

	No	Once	Twice	Three times	Four times	Five or more times
Speeding, less than 10km over the speed limit	○	○	○	○	○	○
Speeding, more than 10km over the speed limit	○	○	○	○	○	○
Not wearing a seat belt	○	○	○	○	○	○
Drink driving	○	○	○	○	○	○
Mobile phone related infringement	○	○	○	○	○	○
Driving through a red light	○	○	○	○	○	○

6. No licence

9. If you do not have a driver's licence, why not?

- ☐ I lost my licence due to infringement
- ☐ I lost my licence due to medical reason
- ☐ I voluntarily choose not to drive

Other (please specify)

7. Driver - collisions

The questions in this section relate to collisions you have had when you were driving. The collision may have involved another road user or have been a single vehicle event. Please attempt to answer all questions, however if you feel that answering a question will be distressing, skip to the next question.

10. In the last 2 years have you been involved in motor vehicle collision as a driver?

- ○ Yes
- ○ No

8. Driver - collisions

11. What was the total number of collisions?

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Cycling safety survey

12. Think about the most recent collision when answering the following questions. Did the collision involve any of the following?

- [ ] Moving motor vehicle
- [ ] Stationary motor vehicle
- [ ] Cyclist
- [ ] Tree or fixed object
- [ ] Pedestrian
- [ ] Bus or tram

Other (please specify)

13. Did the collision result in:

- ○ No injury to any occupants in your vehicle
- ○ Minor injuries (ie not hospitalised) to you or someone else in your vehicle
- ○ Major injuries (ie hospitalised) to you or someone else in your vehicle

Other (please specify)

14. Was the collision officially reported (eg to police, ambulance or hospital)?

- ○ Yes
- ○ No

9. Driver: collision with a CYCLIST

15. Have you EVER been involved in a collision with a cyclist?

- ○ Yes
- ○ No

10. Driver: collision with a CYCLIST

Please answer each question as it relates to the most serious cyclist collision you've had while driving.

16. Was the cyclist travelling in a bicycle lane?

- ○ Yes
- ○ No - no bicycle lane on the road
- ○ No - there was a bicycle lane but the cyclist was not riding in it

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Cycling safety survey

17. Was the cyclist female or male?

- ◯ Female
- ◯ Male

18. Please answer each of the questions below:

	Yes	No	I don't know	N/A
Did you see the cyclist before the collision?	◯	◯	◯	◯
Was the cyclist wearing a helmet?	◯	◯	◯	◯
Was the cyclist injured?	◯	◯	◯	◯
Was the collisions officially reported (eg to police, ambulance, hospital)?	◯	◯	◯	◯
Could the collision have been avoided?	◯	◯	◯	◯

19. If the cyclist was injured, how severe were the cyclist's injuries?

- ◯ No treatment needed
- ◯ Treated by ambulance at the incident location
- ◯ Taken to hospital emergency
- ◯ Admitted to hospital

Other (please specify)

20. Who do you believe was responsible for the incident?

- ◯ Myself
- ◯ Cyclist
- ◯ Both myself and cyclist
- ◯ Neither

Other (please specify)

21. Do you think this incident changed the way you drive when interacting with cyclists?

- ◯ Yes
- ◯ No

11. Driver: cycling infrastructure

The questions in this section relate to on-road bicycle infrastructure. A diagram has been provided for some infrastructure types.

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Cycling safety survey

22. When you are driving on a road with a white painted bike lane you can:

	True	False	Don't know
Drive in the bike lane to undertake a turning car	◯	◯	◯
Drive in the bike lane if there are no bikes or parked cars in it	◯	◯	◯
Drive in the bike lane for 50m to manoeuvre around other vehicles	◯	◯	◯
Not enter the bike lane at any time, this space is for cyclists	◯	◯	◯
Enter when the bike lane is a dashed line	◯	◯	◯

23. When you are driving on a road with a green painted bike lane you:

	True	False	Don't know
Are allowed to drive in the lane at any time	◯	◯	◯
Need to keep out of the lane at all times	◯	◯	◯
Need to be aware of cyclists, this is a complex portion of road	◯	◯	◯

24. When a bike lane ends and there are no markings on the road where should a cyclist ride?

	True	False	Don't know
Cyclists should not be on roads with no line markings	◯	◯	◯
Cyclists should keep to the left at all times on all roads	◯	◯	◯

12. Driver: infrastructure

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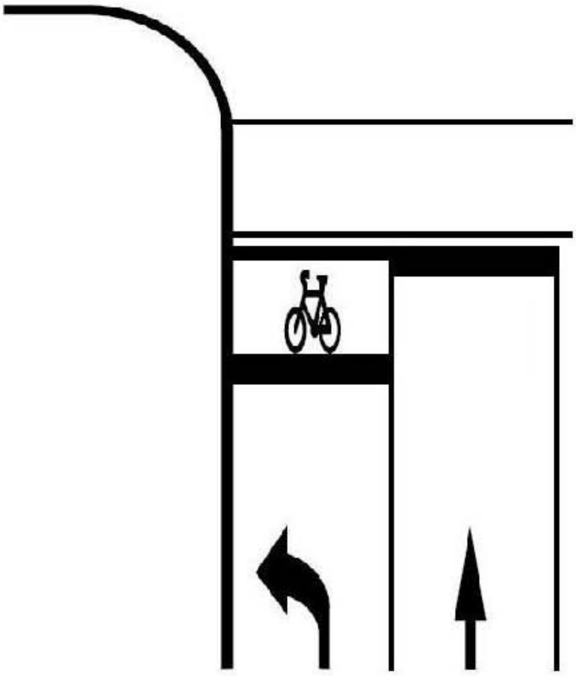
Cycling safety survey

The image below is of a bicycle storage box. These are at some signalled intersections.



25. When you arrive as a DRIVER at an intersection with a bicycle storage box can you:

	True	False	Don't know
Stop in the bike storage box, you only need to keep it clear if cyclists are already there	◯	◯	◯
Stop before the bike storage box, you need to keep it clear at all times	◯	◯	◯
Stop in the bike storage box if you are turning left	◯	◯	◯

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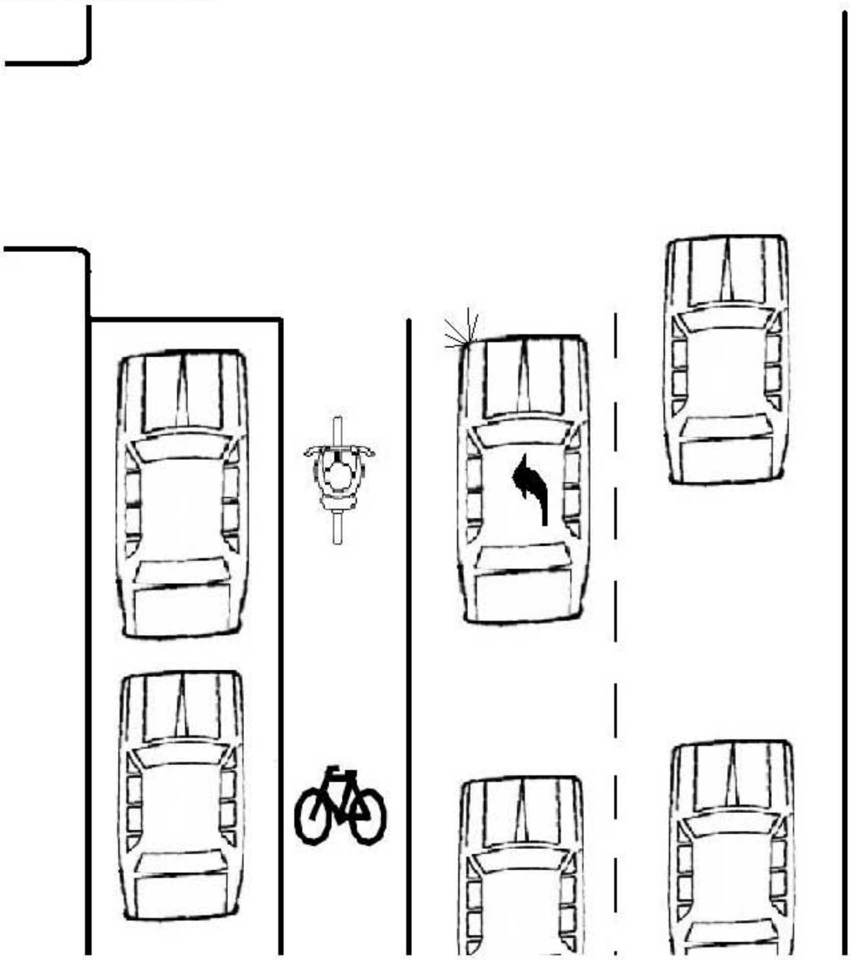
Cycling safety survey

Imagine in the diagram below you are DRIVING the vehicle with the left turn arrow indicating to turn left.



26. Do you:

- ◯ Turn left in front of the cyclist
- ◯ Slow down and wait for the cyclist to cross before turning

Other (please specify)

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Cycling safety survey

27. In the above scenario, who has right of way?

- Driver
- Cyclist
- Depends on the speed limit
- Depends on how fast I am travelling
- Depends on how fast the cyclist is travelling

Other (please specify)

13. Driving with cyclists

All questions in this section relate to road rules in your state or territory.

28. How do you feel about driving on the roads with cyclists?

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
I feel comfortable driving with cyclists when there are no line markings for cyclists	○	○	○	○	○
I try to overtake cyclists as quickly as possible	○	○	○	○	○
I think cyclists are unpredictable	○	○	○	○	○
I feel comfortable driving with cyclists on the road when there are line markings for cyclists	○	○	○	○	○
I feel frustrated when I have to keep passing the same cyclist	○	○	○	○	○
I am more cautious when there are cyclists on the road	○	○	○	○	○

29. How do you feel about other road users?

	Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree
Most drivers look out for cyclists	○	○	○	○	○
Cyclists should be allowed to ride on the road	○	○	○	○	○
Most cyclists ride safely	○	○	○	○	○
Most drivers occasionally disobey road rules	○	○	○	○	○
Most cyclists occasionally disobey road rules	○	○	○	○	○
Cyclists should be fined the same amount as drivers for all traffic infringements	○	○	○	○	○

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Cycling safety survey

30. When arriving at an intersection with traffic lights, how often do you think:

	Never	Seldom	Sometimes	Often	Always	Don't know
Drivers accelerate towards an amber light	○	○	○	○	○	○
Drivers drive through red lights	○	○	○	○	○	○
Cyclists accelerate towards an amber light	○	○	○	○	○	○
Cyclists ride through red lights	○	○	○	○	○	○
Pedestrians walks when the red pedestrian light is flashing	○	○	○	○	○	○
Pedestrians walk against the red pedestrian light	○	○	○	○	○	○

31. How much space do you need to give cyclists to overtake safely? (you may tick more than one response)

- ☐ Depends on how wide the road is
- ☐ Depends on the type of cyclist
- ☐ Half a metre
- ☐ at least 1 metre
- ☐ 2 metres
- ☐ A car width
- ☐ Depends on how fast I'm travelling
- ☐ Depends on how fast the cyclist is travelling
- ☐ Depends on the speed limit of the road

Other (please specify)

32. Adult cyclists are permitted by law to:

	True	False	Don't know
Ride 2 abreast on all roads	○	○	○
Lane split (travel between two lanes of moving vehicle traffic)	○	○	○
Roll through to the front of stationary traffic waiting at a red traffic signal	○	○	○
Ride on the footpath	○	○	○
Ride in dedicated bus lanes	○	○	○

14. Driving with cyclists

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Cycling safety survey

33. On average, how fast do you think the following cyclists travel:

	5-10km/hr	11-20km/hr	21-30km/hr	31-40km/hr	41-50km/hr	51-60km/hr	61-70km/hr	Over 70km/hr	Don't know
A single cyclist riding on a flat road	◯	◯	◯	◯	◯	◯	◯	◯	◯
A single cyclist riding downhill	◯	◯	◯	◯	◯	◯	◯	◯	◯
A group of 8 cyclists riding on a flat road	◯	◯	◯	◯	◯	◯	◯	◯	◯
A group of 8 cyclists riding downhill	◯	◯	◯	◯	◯	◯	◯	◯	◯

34. When driving, how long before turning do you need to indicate?

◯ 2 seconds

◯ 5 seconds

◯ 10 seconds

◯ 2 'blinks'

◯ 6 'blinks'

◯ I don't need to if there's no traffic around

Other (please specify)

35. When driving, do you make a head check (turn your head to the left) before turning left?

◯ Never

◯ Sometimes

◯ Always

36. Motorcyclists are permitted to travel in on-road bike lanes

◯ True

◯ False

◯ I don't know

37. Do you think cyclists should be registered?

◯ Yes

◯ No

Cycling safety survey

38. In your opinion, how effective are each of the following measures in improving safety for cyclists on the road?

	Very ineffective	Ineffective	Neither effective nor ineffective	Effective	Very effective
White line bike lanes	○	○	○	○	○
Coloured bike lanes	○	○	○	○	○
Bicycle storage boxes	○	○	○	○	○
Bicycle phase traffic lights	○	○	○	○	○
Front lights on bikes	○	○	○	○	○
Flashing rear lights on bikes	○	○	○	○	○
Highly visible clothing	○	○	○	○	○
Bicycle helmet	○	○	○	○	○

15. Cycling experiences

In this section you will be asked questions about your experiences related to riding.

39. Do you consider yourself to be a cyclist?

○ Yes

○ No

40. Please briefly describe who a 'cyclist' is:

41. How many bicycles do you own?

42. How many bicycles are in your household?

43. Do you ride a bicycle?

○ No (you may or may not have ridden a bicycle as a child, but now you're an adult you do not ride a bicycle)

○ Yes, I ride occasionally

○ Yes, I often ride my bike

Other (please specify)

16. Cycling experiences

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Cycling safety survey

44. When you are riding do you:

	Never	Seldom	Sometimes	Often	Always
Ride on the road	○	○	○	○	○
Ride on the footpath	○	○	○	○	○
Ride on the footpath when riding with children	○	○	○	○	○
Ride on off-road bike paths	○	○	○	○	○
Wear a helmet	○	○	○	○	○
Wear headphones	○	○	○	○	○
Use a mobile phone to receive calls/texts	○	○	○	○	○
Use a mobile phone to make calls/send texts	○	○	○	○	○
Indicate (hand signal) when turning left	○	○	○	○	○
Indicate (hand signal) when turning right	○	○	○	○	○
Obey road rules	○	○	○	○	○
Obey road signs	○	○	○	○	○
Stop at red lights	○	○	○	○	○
Use a bell	○	○	○	○	○

45. When would you ride through a red light?

- [ ] I always ride through red lights
- [ ] I never ride through a red light
- [ ] When trying to cross on the amber and it turns red
- [ ] When turning left
- [ ] At a pedestrian crossing
- [ ] When I'm in a hurry

Other (please specify)

46. When would you stop at a red light?

- [ ] I always stop
- [ ] When there's too much traffic to cross safely
- [ ] When there's a driver waiting at the traffic light
- [ ] When there's another cyclist waiting at the traffic light

Other (please specify)

17. Cyclist: infrastructure

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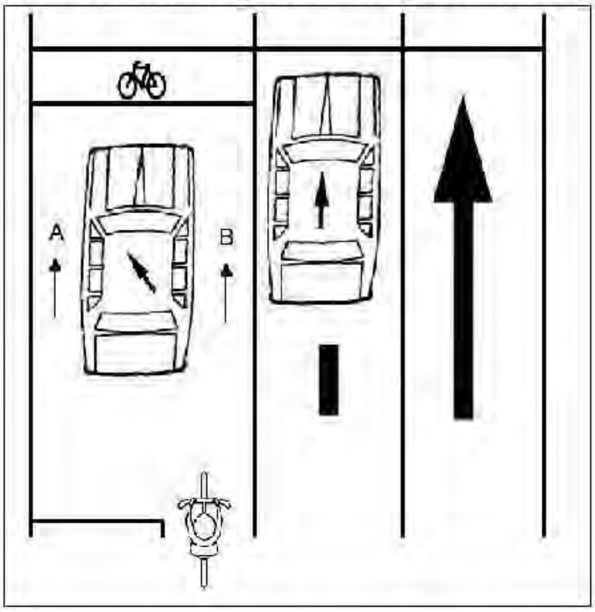
Cycling safety survey

Imagine you are the CYCLIST in the diagram below.
The left vehicle has stopped for a red signal and is indicating to turn left.



47. You are the CYCLIST in the diagram above, when you approach the intersection, do you:

- [ ] Pass the left vehicle on the left side (side A) and wait in the bike storage box
- [ ] Pass between the left vehicle and the vehicle in the centre lane (side B) and wait in the bike storage box
- [ ] Stop behind the turning vehicle

Other (please specify)

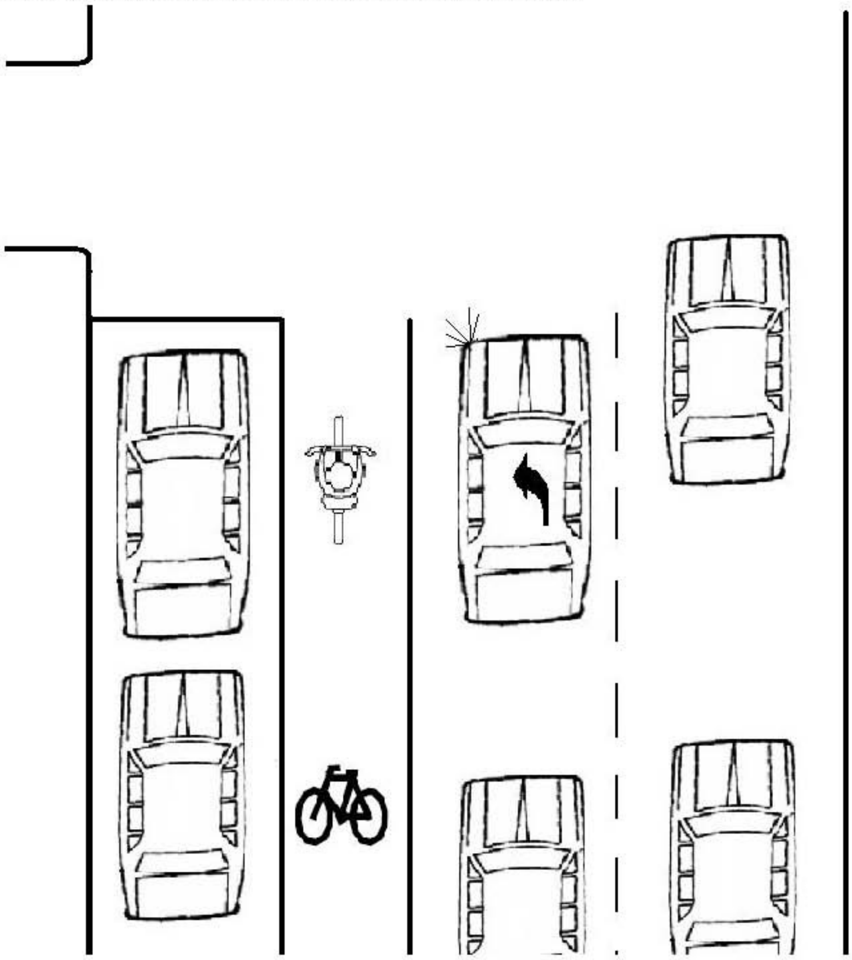
48. Why did you choose that option?

- [ ] It's the safest option
- [ ] It's the only legal option
- [ ] It's what I usually do
- [ ] I don't know

Other (please specify)

Cycling safety survey

In the diagram below you are RIDING in the bike lane, the driver to your right is indicating to turn left. (the cars on the left side are parked)



49. Do you:

- ◯ Keep cycling and pass in front of the turning vehicle
- ◯ Slow down and wait for the vehicle to turn before continuing

Other (please specify)

18. Cycling experiences

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Cycling safety survey

50. What type of bike do you usually ride on the road?

- ☐ Road bike
- ☐ Mountain bike
- ☐ Hybrid bike
- ☐ Ladies (comfort) bike
- ☐ Single speed bike (with free wheel)
- ☐ Fixed gear bike (ie track bike)
- ☐ Folding bike
- ☐ Recumbent bike
- ☐ BMX

Other (please specify)

51. What is the main reason you ride a bike?

52. During WARM months how often do you ride:

	Never	Less than once a month	Once a month	A couple of times a month	A few time a week	Everyday
To commute to and from work	☐	☐	☐	☐	☐	☐
For recreation	☐	☐	☐	☐	☐	☐
For fitness/training	☐	☐	☐	☐	☐	☐

53. During COLD months how often do you ride:

	Never	Less than once a month	Once a month	A couple of times a month	A few time a week	Everyday
To commute to and from work	☐	☐	☐	☐	☐	☐
For recreation	☐	☐	☐	☐	☐	☐
For fitness/training	☐	☐	☐	☐	☐	☐

54. How many kilometres do you ride per week?

	None	<10 km	11-50 km	51-100 km	101 - 150 km	151 - 200 km	200+ km
During warmer months	○	○	○	○	○	○	○
During colder months	○	○	○	○	○	○	○

19. Cycling experiences

Cycling safety survey

55. What cycling specific items to you wear/use when you ride your bike?

	Never	Seldom	Sometimes	Often	Always
Lycra cycling shorts/pants	○	○	○	○	○
Cycling jersey	○	○	○	○	○
Cycling shoes (clip in)	○	○	○	○	○
Fluorescent/reflective jacket	○	○	○	○	○
Light coloured clothing	○	○	○	○	○
Lights - during the day	○	○	○	○	○
Lights - at low light/dark times	○	○	○	○	○

56. Do you currently belong to a cycling organisation?

☐ Cycling club

☐ Cycling organisation eg Bicycle Victoria, Bicycle Institute South Australia

☐ No, I don't belong to a cycling organisation

Other (please specify)

57. Have you ever taken a bicycle training course?

○ Yes

○ No

58. Are there any road types/locations that you avoid?

○ Yes

○ No

59. If yes, briefly describe the road type/location

60. If yes, what could be done to improve the location?

20. Cycling collision

Questions in this section ask about collision or near-collision events you have been involved in while riding on the road.

61. While riding on the road have you been involved in a collision with a vehicle?

○ Yes

○ No

Cycling safety survey

62. While riding your bicycle on the road have you ever been involved in a NEAR-collision with a vehicle?

- ◯ Yes
- ◯ No

63. If yes, how many near-collisions with vehicles have you experienced while riding on the road?

21. Cyclist: Most serious collisions/near-collision incident

The following questions in this section ask about the most serious collision or near-collision event you have had while cycling.
Please attempt to answer all questions, however if you feel that answering a question will be distressing, skip to the next question.

64. Were you travelling in a bicycle lane?

- ◯ Yes
- ◯ No - no bicycle lane on the road
- ◯ No - there was a bicycle lane but I was not riding in it

65. Was the driver female or male?

- ◯ Female
- ◯ Male

66. Please answer each of the questions below:

	Yes	No	I don't know	N/A
Did you see the vehicle before the collision?	◯	◯	◯	◯
Were you wearing a helmet?	◯	◯	◯	◯
Were you injured?	◯	◯	◯	◯
Was the collisions officially reported (eg to police, ambulance, hospital)?	◯	◯	◯	◯
Could the collision have been avoided?	◯	◯	◯	◯

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