Title:

Regional Differences in Pedal Cyclist Injuries in New Zealand: Safety in Numbers or Risk in Scarcity?

Authors:

Sandar Tin Tin, Section of Epidemiology and Biostatistics, School of Population Health, University of Auckland, New Zealand. Email: s.tintin@auckland.ac.nz

Alistair Woodward, School of Population Health, University of Auckland, New Zealand. Email: a.woodward@auckland.ac.nz

Simon Thornley, Section of Epidemiology and Biostatistics, School of Population Health, University of Auckland, New Zealand. Email: s.thornley@auckland.ac.nz

Shanthi Ameratunga, Section of Epidemiology and Biostatistics, School of Population Health, University of Auckland, New Zealand. Email: s.ameratunga@auckland.ac.nz

Corresponding Author:

Sandar Tin Tin
Section of Epidemiology and Biostatistics
School of Population Health
University of Auckland
Private Bag 92019
Auckland 1142
New Zealand
Email: s.tintin@auckland.ac.nz
Tel: +64 21 212 5155

Word Count (including abstract and references): 4550

Word Count (main body text): 2818

Abstract

Aim: To assess regional differences in total time spent cycling and travelling in a car and exposure-based risks of traffic injuries to pedal cyclists resulting in death or hospital inpatient treatment

Methods: Cycling injuries were identified from the Mortality Collection and the National Minimum Dataset. Time spent cycling and travelling in a car/van/Ute/SUV (driving or riding as a passenger) was computed from National Household Travel Surveys. There are sixteen census regions in New Zealand, some of which were combined for this analysis to ensure an adequate sample size, resulting in eight regional groups. Analyses were undertaken for 1996-99 and 2003-07.

Results: The risk of injuries per million hours spent cycling varied widely across regions (ranging from 11 to 33 injuries during 1996-99 and from 12 to 78 injuries during 2003-07). The expected number of cycling injuries increased with increasing annual total time spent cycling but at a decreasing rate after adjusting for total time spent driving/riding. The risk of cycling injuries decreased with increasing annual per capita time spent cycling and decreasing annual per capita time spent driving/riding. There was an inverse association between the injury risk and the ratio of time spent cycling to time spent driving/riding.

Conclusion: The findings indicate the “risk in scarcity” effect for New Zealand cyclists, i.e., the risk profiles of cyclists will worsen if less people use a bicycle and more use a car.

Implications: Cooperative efforts to promote cycling and its safety and to restrict car use may reverse the “risk in scarcity” effect.

Key words: Bicycling, Traffic accidents, Exposure-based risk, Safety in numbers

“Safety in numbers” is a well known hypothesis in traffic safety, suggesting that a specific mode of travel may become safer if more people do it. This effect was first demonstrated in 1949 when R.J. Smeed, using data from 62 countries, showed that the fatality risk per vehicle was lower in countries with more vehicles per population.[1] Since then, others have described the same relationship, often referred to as Smeed’s Law, in the UK[2] and Australia[3]. More recent research has reported that the benefits of safety in numbers apply to vulnerable road users such as cyclists and pedestrians.[4-9]

New Zealand is a country with a very high rate of car ownership and use.[10] Between 2005 and 2009, driver and passenger trips accounted for almost 80% of all time spent travelling whereas use of a bicycle represented only 2%.[11] Despite this low share in travel mode, cycling injuries are a concerning public health problem in this highly car dependent society. The New Zealand Ministry of Transport data based on police reports showed that ten cyclists were killed, 186 were seriously injured and many more suffered minor injuries due to crashes on public roads in 2008.[12] The estimated total social cost was about NZ$224 million.[12]

The potential benefits of the safety in numbers effect for New Zealand cyclists were observed in a previous study undertaken between 2002 and 2004.[9] The study showed that the crash rate per cyclists decreased with increasing cycle volume at traffic signals, roundabouts and mid-block sites in three cities. As there are regional variations in travel patterns in New Zealand,[13 14] this paper aimed to investigate if there is a similar effect nationwide.

Methods

There are a total of sixteen regions in New Zealand defined at meshblock and area unit levels. A meshblock is the smallest geographic area for which statistical data is collected and processed.[15] We compared total time spent cycling and travelling in a car and the risk of traffic injuries to pedal cyclists resulting in death or hospital inpatient treatment across regions for 1996-99 and 2003-07. For this analysis, in accordance with Ministry of Transport guidelines, some of the regions were combined to ensure an adequate sample size (i.e., 30 people or more), resulting in eight regional groups.

Data sources

The data for this analysis were obtained from the Mortality Collection and the National Minimum Dataset maintained by the Ministry of Health's Information Directorate and the Household Travel Survey Dataset maintained by the Ministry of Transport.

Mortality Collection: This contains information about all deaths registered in New Zealand. The data collected include demographic information and the underlying cause of death coded according to the *International Classification of Diseases (ICD)*.[16] ICD-9-CMA was used before 2000 and ICD-10-AM afterward.

National Minimum Dataset: This contains information about all day patients and inpatients discharged from public and private hospitals in New Zealand. The data collected include demographic information, diagnoses and diagnostic and therapeutic procedures. For all injury discharges, the circumstances of injury are coded according to the external causes of injury and poisoning codes (E codes) and the nature of injury is coded according to the *ICD*.[16] ICD-9-CMA was used before July 1999 and ICD-10-AM afterward.

Household Travel Surveys: Three separate national surveys[17] have collected information on daily personal travel in New Zealand. This analysis was restricted to the last two surveys as the first survey undertaken in 1989-90 did not have regional information. The second survey was carried out in 1997-98 and included over 14,000 people of all ages. From mid 2003, an ongoing survey has been conducted each year, with the sampling frame comprising approximately 2,000 households (resulting in responses from about 3500 people per year).

Statistical Analysis

The risk of traffic injuries among pedal cyclists resulting in death or hospital inpatient treatment was calculated using exposure-based methods:

$$\text{Risk} = \frac{\text{Number of cases of cycling injuries}}{\text{Exposure}}$$

Traffic injuries (i.e., injuries occurring on a public highway) among pedal cyclists were identified from the Mortality Collection and the National Minimum Dataset using the E-codes (ICD-9-CMA: E810-819.65, E826.15, E826.95, E829-829.15; and ICD-10-

AM: V10-18.3-9, V19.4-6, V19.9). The subset of these injuries that resulted from a collision with a motor vehicle were identified using the E-codes (ICD-9-CMA: E810-819.6; ICD-10-AM: V12-V14.3-9, V19.4-6).[16] The hospitalised sample was restricted to inpatient discharges from public hospitals as the majority of patients (over 97%) requiring acute inpatient treatment for injury are admitted to public hospitals.[18-20] In order to enhance the validity of the analyses, the inclusion criteria included: (a) patients with a principal diagnosis of injury only (ICD-10-AM: S00-T78), (b) patients admitted to hospital for one day or more and (c) first admissions only.[19]

The required travel exposure variables (annual total and per capita time spent cycling and driving or riding as a passenger in a car/van/Ute/SUV) were computed from the 1997-98 and 2003-08 travel survey datasets. The data were weighted to account for clustering by household and non-response to the survey.

The relationship between the number of injuries to pedal cyclists and annual total time spent cycling and driving/riding was measured using the power function $I = b_0 x_1^{b1} x_2^{b2}$ (that has been used in previous research[9 21 22]), where I is the number of injuries to pedal cyclists, x_1 and x_2 are total time spent cycling and driving/riding respectively and b_0, b_1 and b_2 are model parameters to be computed.

The association between the risk of injuries to pedal cyclists and annual per capita time spent cycling and driving/riding and the ratio of time spent cycling to time spent driving/riding was calculated using log-linear models. Given concerns about the use of ratio variables containing common terms (i.e., time spent cycling),[23] part correlation was undertaken to check for the possibility of spurious associations between injury risk and per capita time spent cycling and the ratio of time spent cycling to time spent driving/riding.[24 25]

To minimise the effect of extraneous factors such as service utilisation, a sensitivity analysis was undertaken by restricting cases of interest to those with serious injuries[26] (an Abbreviated Injury Scale (AIS)[27 28] score of 3 or more). The mapping to AIS threshold was achieved using the Barell matrix categorisation.[29] The ICD-10-AM codes were mapped into the ICD-9-CM codes for this purpose. SAS (release 9.1, SAS Institute Inc., Cary, NC) and Microsoft Office Excel 2003 were used for all analyses.

Results

Annual per capita time spent cycling varied widely across regions, ranging from 2.7 hours in Northland-Auckland to 12.8 hours in Canterbury during 1997-98 and from 2.0 hours in Northland-Auckland to 13.3 hours in Tasman-Nelson-Marlborough during 2003-08. Annual per capita time spent driving or riding as a passenger ranged from 135.2 hours in Tasman-Nelson-Marlborough to 209.3 hours in Northland-Auckland during 1997-98 and from 170.5 hours in Tasman-Nelson-Marlborough to 222.5 hours in Northland-Auckland during 2003-08.

The risk of traffic injuries to pedal cyclists varied across regions, from 11 injuries per million hours spent cycling in Wellington to 33 injuries per million hours spent cycling in Northland-Auckland during 1996-99; and from 12 injuries per million hours spent cycling in Tasman-Nelson-Marlborough to 78 injuries per million hours spent cycling in Northland-Auckland during 2003-07 (Figure 1). Similar patterns were observed for the risk of cycling injuries resulting from a collision with a motor vehicle.

The expected number of injuries to pedal cyclists increased with increasing annual total time spent cycling (Table 1, Figure 2). However, this effect occurred at a decreasing rate if time spent driving/riding was kept constant. The increase in total time spent driving/riding significantly increased the number of cycling injuries even after adjusting for time spent cycling.

The risk of injuries to pedal cyclists decreased with increasing annual per capita time spent cycling (Table 2, Figure 3). The association did not disappear in part correlation analysis (Table 3). The cycling injury risk increased with increasing per capita time spent driving/riding particularly during 2003-07. A significant inverse association was observed between injury risk and the ratio of time spent cycling to time spent driving/riding, indicating that the safety benefits of increasing cycling could be attenuated by increasing car use.

The findings were similar when analyses were restricted to those with serious injuries (estimated AIS score of 3 or more).

Discussion

Our findings show wide variation in the amount of cycling and driving or riding as a passenger in a car/van/Ute/SUV and the risk of traffic injuries to pedal cyclists across

New Zealand regions. Cyclists were safer in regions with more bicycle use and less car use.

The major strength of this study is the use of data from three national datasets to make within-country comparisons of exposure-based risks of cycling injuries resulting in death or hospital inpatient treatment and travel exposure variables of interest. However, some limitations should be kept in mind when interpreting the findings. Relatively minor injuries treated in emergency departments, private primary care facilities or self-treated were not included in this analysis. It has been proposed that such injuries be excluded in developing indicators of injury incidence due to incomplete ascertainment.[26] While these injuries may not pose a significant threat to life, it cannot be assumed that they will not pose a threat to longer-term disability. Ascertainment of relevant cases could also be affected by inaccuracies in diagnosis and external cause codes. Some reports suggest that up to a quarter of the E-codes assigned to hospital discharges could be incorrect at the level of the 4th digit.[30 31] However, these inaccuracies are considered to be most likely for death records, particularly among older people.[26 32 33] Admission to hospital may be influenced by a number of factors including severity of injury, pre-existing co-morbidities, access to hospital services, professional practice and bed/theatre availability.[26] While it was reassuring to note similar associations when analyses were restricted to serious injuries as classified by the Barell matrix, it is acknowledged that misclassification of injury severity could remain an issue with this approach.[34] Finally, there is a possibility of spurious associations in analyses involving ratio variables with a common term (i.e., time spent cycling);[23] however, the associations did not disappear after controlling for the effect of the common term.

Despite these limitations, our findings contribute to the limited research on the safety in numbers effect for vulnerable road users. The earliest published studies examining this effect were conducted in Sweden.[4 5] Ekman compared numbers of cyclists, pedestrians and motorists against serious conflicts/crashes among them at 95 intersections in Malmö and found an inverse relationship between the number of conflicts per cyclists and the number of cyclists per hour.[4] Likewise, Leden et al examined bicycle flow counts and collisions between motorists and bicyclists before and after the construction of a new design of a bicycle crossing at 45 non-signalised intersections in Gothenburg and reported that the number of collisions per bicyclists decreased with increasing bicycle flow.[5] Using five independent datasets from the US and Europe, Jacobsen concluded that a cyclist's or pedestrian's risk of being struck by a motor vehicle (per capita injury or fatality rate) varied with the -0.6 power of the amount of cycling or walking (measured by the portion of the journey to work on foot/bicycle, per capita distance walked/bicycled per day, and per capita trips on foot/bicycle per day).[7] Robinson examined three Australian datasets and found a similar association between fatalities per distance cycled and average per capita distance cycled.[8]

Behaviour change by motorists is considered the most likely mechanism which underlies the safety in numbers effect.[7] This theory was formulated after researchers observed motorists drive more slowly when they encounter more pedestrians and faster when there are few.[35] Moreover, if more people cycle, drivers are more likely to be cyclists themselves and may give more consideration to other road users.[7] Such a situation is likely to also result in greater political will to improve the traffic environment in favour of cyclists.[8 36]

In New Zealand, the amount of cycling relative to the amount of motorised traffic appears to be an important determinant of cycling injury risks. Our study as well as previous research[9 37] reveals that the expected number of cycling injuries increases with increasing the amount of cycling but at a decreasing rate (i.e., the injury risk decreases) after adjusting for the amount of car use. For example, at the current level of car use (1184 million hours per year[14]), doubling the amount of cycling (24 million hours per year currently[14]) will result in 88 more cycling injuries and tripling the amount of cycling will result in 144 more injuries. This will be more pronounced if car use decreases – at half the current level of car use (i.e., 592 million hours per year), doubling cycle use will result in 50 more injuries and tripling cycle use will result in 81 more injuries. This is also evidenced in our analysis showing an inverse association between the injury risk and the ratio of time spent cycling to driving/riding. Indeed, given the decline in cycle use relative to car use in most regions, we could more appropriately label this effect “risk in scarcity”.

Both volume and speed of motorised traffic pose risks to vulnerable road users. Previous research reported a positive association between vehicle flow and pedestrian injury risk.[4 6] Likewise, the risk that speeding places on pedestrians, cyclists and other vulnerable road users has been well recognised.[38] Consequently, increasing traffic volume and speed discourages people to engage in active travel.[39] For example, in a recent survey by Chinese state television, almost half of cyclists reduced their use of this travel mode mainly due to increased perceived danger in the streets.[40] The vicious circle that would arise from an increasingly dangerous road environment encouraging greater car use poses a higher risk for those who continue cycling or walking and will have the greatest impact on those who lack access to a car, e.g., children, the elderly and low-income families.

Reversing the “risk in scarcity” effect requires cooperative efforts to promote a modal shift (from using cars to active travel modes) and to improve the safety of vulnerable road users. Of interventions which aim to influence transport choices, targeted behaviour change programmes appear to be effective in motivated subgroups but the evidence for publicity campaigns, engineering measures, financial incentives and providing alternative services is inconsistent and insufficient.[41] Of interventions which aim to make cycling safer, helmet use reduces the risk of head, brain and facial injuries in a crash.[42] Visibility aids improve detection and recognition by drivers but its effect on cyclist safety remains unclear.[43] A recent cross-sectional study reported that low cyclist conspicuity increased the risk of cycle crash injuries.[44] Environmental measures such as purpose-built cycle-only facilities,[45] street lighting,[46] area-wide traffic calming[47] and speed limits[48] are likely to improve traffic safety. However, research to date has tended to concentrate on only one set of outcomes, either travel behaviour or injury risk, so that little is known about the effects of such measures on both outcomes.[49] There are many reasons to address this gap in knowledge, including the argument raised by some that traffic safety efforts such as compulsory cycle helmet legislation may discourage bicycle use.[50]

The success of European countries in promoting cycling and walking highlights the importance of “coordinated implementation of the multi-faceted, mutually reinforcing set of policies”, such as provision of better facilities for pedestrians and cyclists, extensive traffic calming of residential neighbourhoods, increased traffic regulation and enforcement, people oriented urban design, integration of active travel with public transport, comprehensive traffic education and training and restrictions on car ownership, use and parking.[51 52]

In auto-centric countries like New Zealand, significant barriers exist to implementing such comprehensive measures but much could be achieved in the short term. We found an increasing trend in cycling and a decreasing trend in cycling injury risk in regions (e.g., Nelson[53]) that have invested in sustainable transport strategies. Given that the convenience of car use is one of the main reasons why New Zealanders don’t cycle and walk,[54] car restrictive measures, although often perceived as less important than measures for cycling promotion,[55] deserve more attention. Possible actions include: congestion charging,[56] Pay-As-You-Drive vehicle insurance,[57] environmental levies on petrol, road closures, car-free zones and car park restrictions. Our analysis shows that if cycle use remains constant and car use is reduced by 10%, there will be 56 fewer admissions to hospital for cycling injuries annually.

A modal shift from car use to cycling also improves safety to other road users[64] and provides substantial health, environmental and economic benefits. Obesity rates are lower in countries where active travel is more common[58]. There is evidence showing that active commuting reduces the risk of mortality[59] [60] or cardiovascular events[61], enhances social cohesion, community livability and transport equity,[62-64] saves fuel and reduces motor vehicle emissions.[65]

Conclusion

In New Zealand, the risk of injuries to pedal cyclists and the amount of cycling relative to car use are linked, consistent with a 'risk in scarcity' effect. This means that the risk profiles of cyclists will worsen if less people use a bicycle and more use a car.

Acknowledgement

We thank Mr Robert Hipkiss at the Ministry of Health for providing mortality and hospitalisation data, Ms Lynley Povey at the Ministry of Transport for providing Household Travel Survey data, Mr Brandon de Graaf at the Injury Prevention Research Unit, University of Otago for advising how to identify readmission cases and Mrs Elizabeth Robinson at the Epidemiology and Biostatistics for her statistical advice.

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Table 1. Relationship between the number of traffic injuries to pedal cyclists and time spent cycling and driving/riding

Travel exposure variables	Number of overall injuries						Number of collisions with a motor vehicle					
	Crude			Adjusted*			Crude			Adjusted*		
	Estimate	SE	p-value	Estimate	SE	p-value	Estimate	SE	p-value	Estimate	SE	p-value
Time spent cycling per year												
1996-99	0.82	0.22	0.01	0.25	0.20	0.27	0.68	0.32	0.08	-0.14	0.26	0.61
2003-07	0.91	0.49	0.11	0.18	0.18	0.37	0.92	0.49	0.11	0.25	0.29	0.44
Time spent driving/riding per year												
1996-99	0.68	0.10	0.0004	0.54	0.15	0.01	0.70	0.12	0.0009	0.78	0.19	0.01
2003-07	0.88	0.09	<0.0001	0.82	0.11	0.001	0.84	0.15	0.001	0.76	0.18	0.01

* - adjusted for both exposure variables in the table

Table 2. Relationship between the risk of traffic injuries to pedal cyclists and time spent cycling and driving/riding

Travel exposure variables	Risk of overall injuries			Risk of collisions with a motor vehicle		
	Estimate	SE	p-value	Estimate	SE	p-value
Per capita time spent cycling per year						
1996-99	-0.09	0.03	0.02	-0.13	0.04	0.02
2003-07	-0.13	0.03	0.002	-0.11	0.04	0.03
Per capita time spent driving/riding per year						
1996-99	0.002	0.005	0.6	0.002	0.007	0.8
2003-07	0.014	0.006	0.05	0.015	0.005	0.03
Ratio of time spent cycling to driving/riding						
1966-99	-23.83	8.46	0.03	-33.18	12.89	0.04
2003-07	-36.70	6.16	0.001	-31.36	9.90	0.02

Table 3. Part correlation

Travel exposure variables	Risk of overall injuries			Risk of collisions with a motor vehicle		
	Estimate	SE	p-value	Estimate	SE	p-value
Per capita time spent cycling per year						
1996-99	-0.09	0.03	0.02	-0.14	0.04	0.01
2003-07	-0.12	0.06	0.08	-0.10	0.06	0.1
Ratio of time spent cycling to driving/riding						
1966-99	-26.41	8.88	0.02	-38.85	12.59	0.02
2003-07	-31.89	14.41	0.07	-22.12	17.17	0.2

Figure 1. Risks of overall and collision injuries to pedal cyclists by region

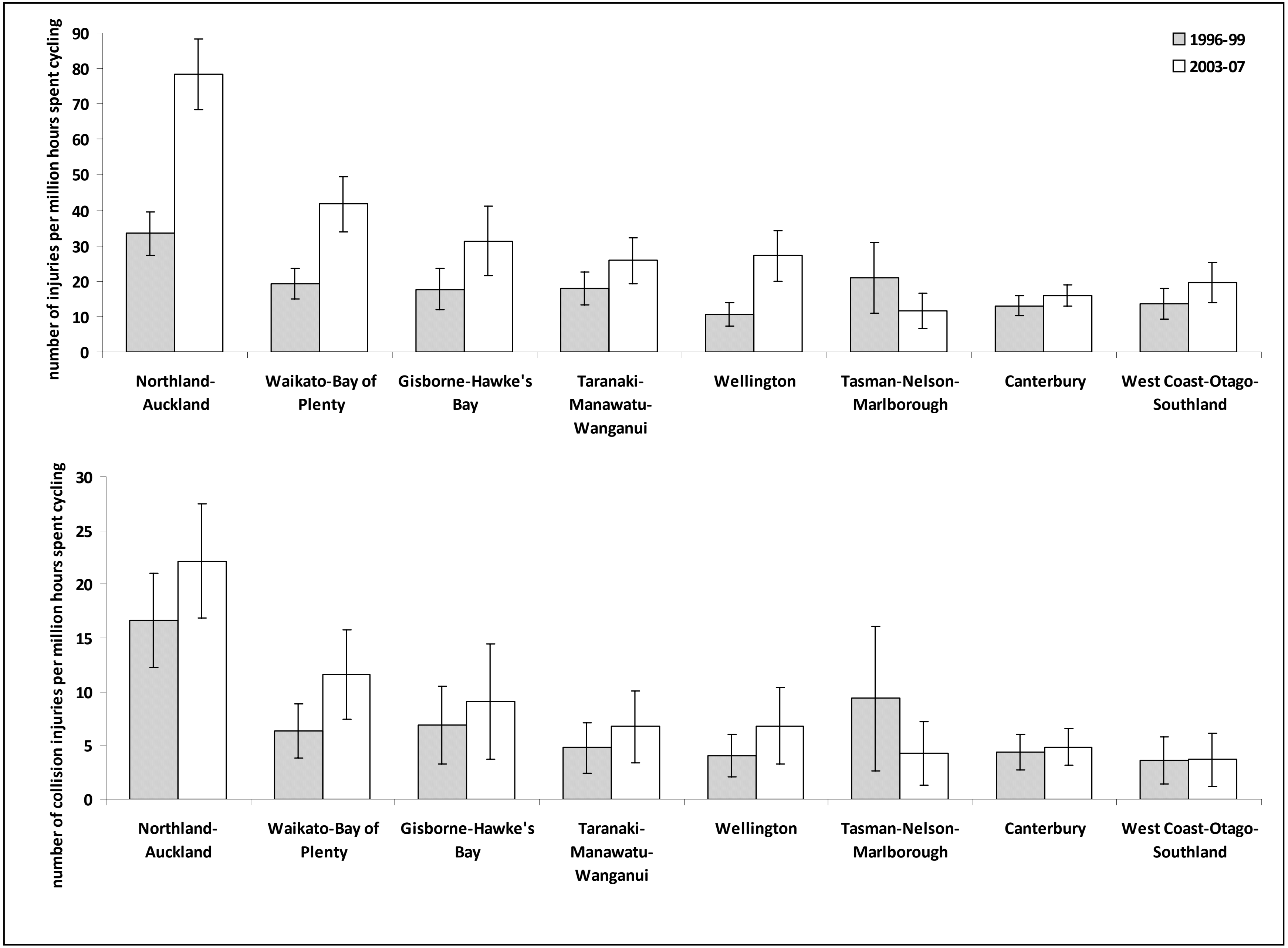
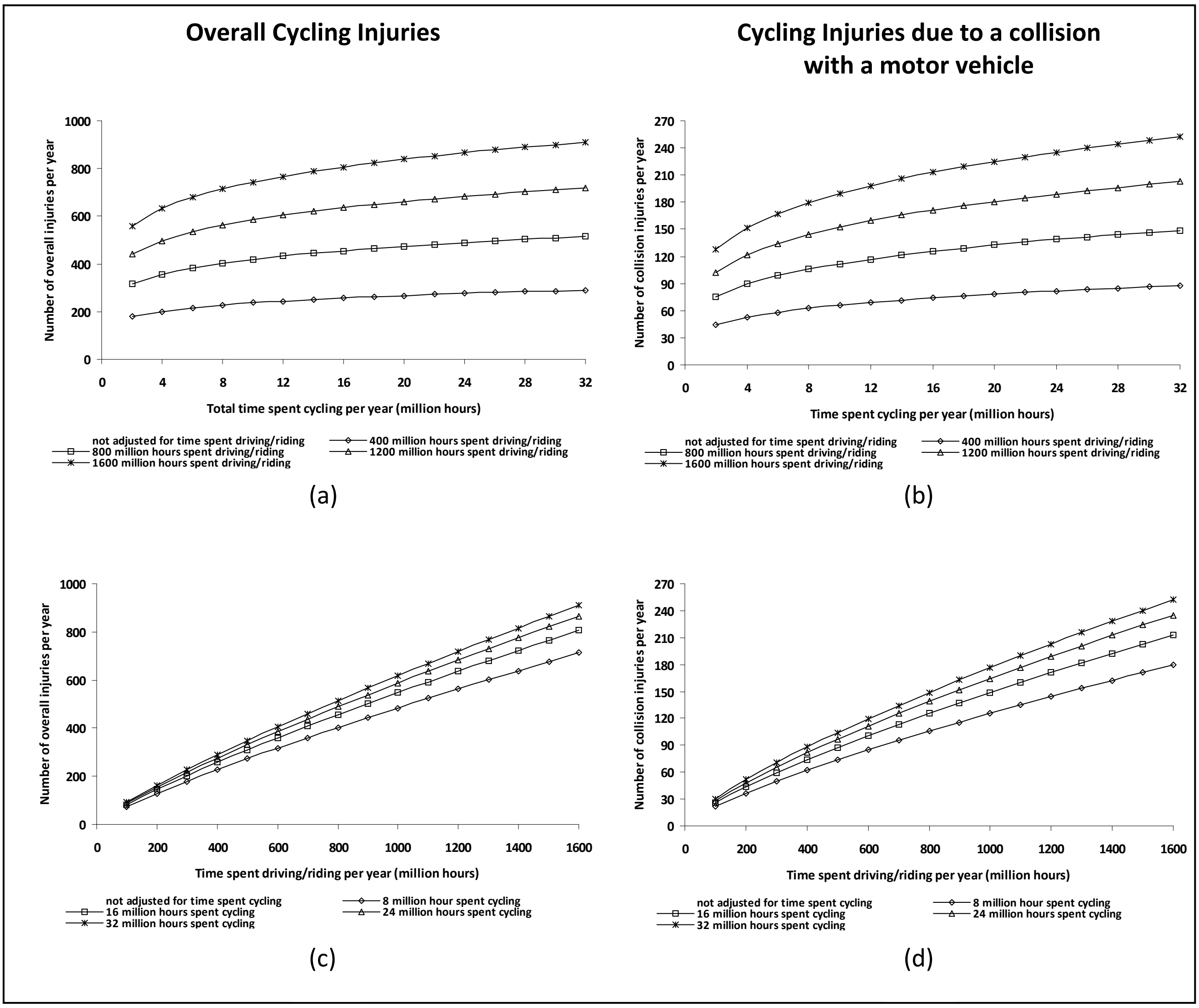
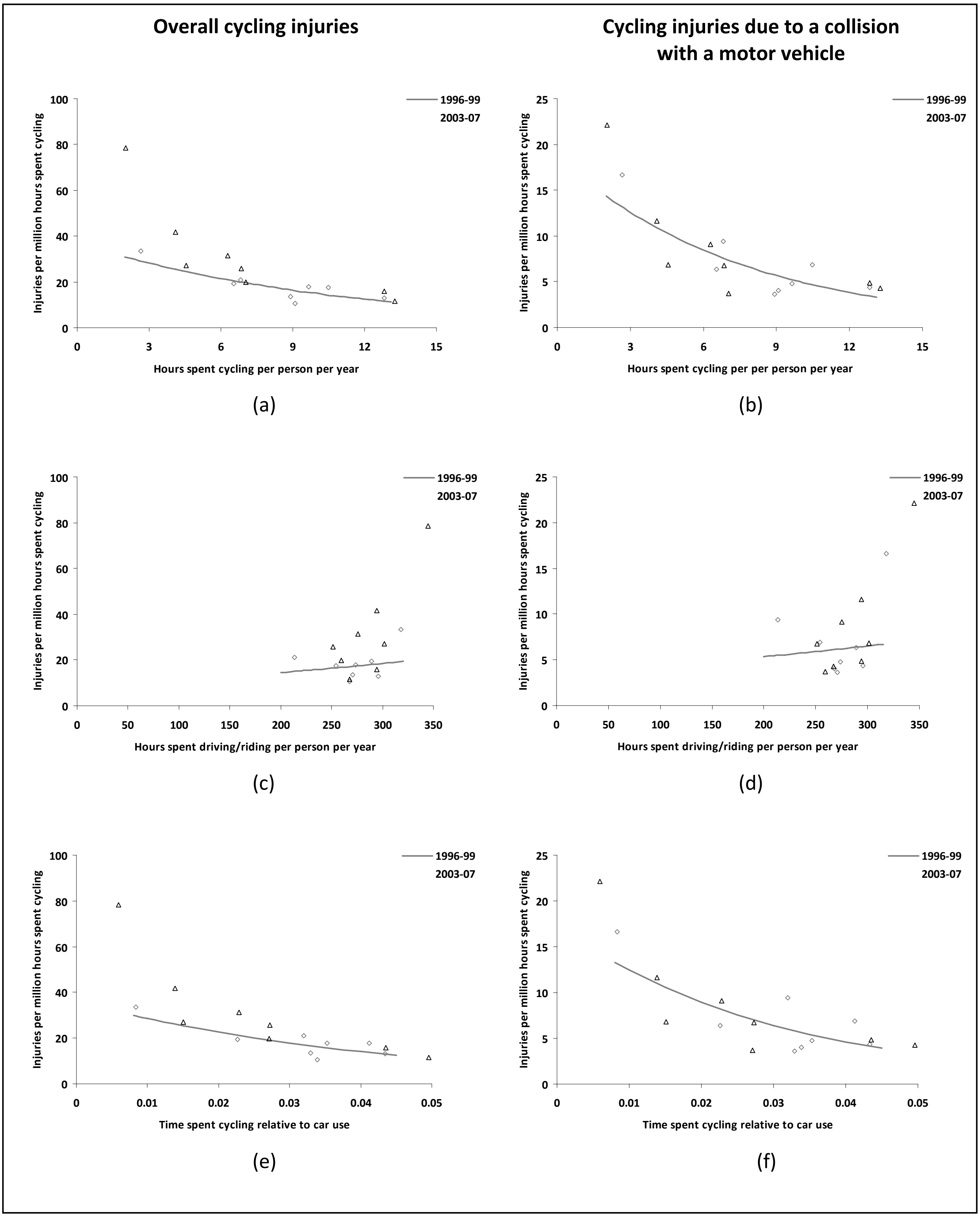


Figure 2. Relationship between the number of traffic injuries to pedal cyclists and time spent cycling and driving/riding (2003-07)



(a) and (b) – injuries with changing time spent cycling
(c) and (d) – injuries with changing time spent driving/riding

Figure 3. Relationship between the risk of traffic injuries to pedal cyclists and time spent cycling and driving/riding



(a) and (b) – injury risk with per capita time spent cycling
(c) and (d) – injury risk with per capita time spent driving/riding
(e) and (f) – injury risk with time spent cycling relative to driving/riding