Title:

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

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Abstract

Objective: To assess regional variations in rates of traffic injuries to pedal cyclists resulting in death or hospital inpatient treatment, in relation to time spent cycling and time spent travelling in a car.

Method: Cycling injuries were identified from the Mortality Collection and the National Minimum Dataset. Time spent cycling and time spent travelling as a driver or passenger in a car/van/Ute/SUV were 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: Injury rates, 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 injury rate increased with decreasing per capita time spent cycling. The rate also increased with increasing per capita time spent travelling in a car. There was an inverse association between the injury rate and the ratio of time spent cycling to time spent travelling in a car. The expected number of cycling injuries increased with increasing total time spent cycling but at a decreasing rate particularly after adjusting for total time spent travelling in a car.

Conclusion: The findings indicate the “risk in scarcity” effect for New Zealand cyclists that risk profiles of cyclists are likely to deteriorate if fewer 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 concept in traffic safety, suggesting that a specific mode of travel may become safer if more people do it. Such a relationship was first reported 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 made the same observation, often referred to as Smeed's Law, in the UK[2] and Australia[3].

The safety in numbers phenomenon applies also to vulnerable road users such as cyclists and pedestrians.[4-9] This has important public health and road safety implications as active modes of travel provide substantial health, environmental and economic benefits. For instance, obesity rates are lower in countries where active travel is more common.[10] Active commuting reduces mortality[11,12] and the rate of cardiovascular events,[13] enhances social cohesion, community livability and transport equity,[14-16] improves safety to other road users,[17] saves fuel and reduces motor vehicle emissions.[18] Despite this, active travel in general, and cycling in particular, remain marginal modes of transport in many countries. One of the major barriers to cycling is fear of injury.[19,20] In this situation, the safety in numbers effect, might be an important multiplier of benefits in promoting cycling and its safety.

New Zealand is a country with a very high rate of car ownership and use.[21] 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%.[22] The most recent (2008) data from the New Zealand Ministry of Transport, 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.[23] The estimated total social cost was about NZ$224 million.[23]

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. To supplement this, we investigated if there is a similar effect nationwide using information from three national datasets. As there are regional variations in travel patterns in New Zealand,[24,25] our specific research questions include: (a) does the rate of injuries to pedal cyclists per hour of travel vary by region?; and (b) is the variation in such rate, if any, associated with the variation in time spent cycling and time spent travelling in a car across regions?.

Methods

There are a total of sixteen regions in New Zealand defined at meshblock (the smallest geographic area for which statistical data is collected and processed[26]) and area unit levels. For this analysis, in accordance with Ministry of Transport guidelines, some of the regions were combined to ensure an adequate sample size (i.e., at least 30 people reported cycling), 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 from 1988 onwards. The data collected include demographic information and the underlying cause of death coded according to the *International Classification of Diseases (ICD)*.[27] 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*.[27] ICD-9-CMA was used before July 1999 and ICD-10-AM afterward.

Household Travel Surveys: Three separate national surveys[28] have collected information on daily personal travel, with the sampling frame comprising all residents (including children) in private dwellings in New Zealand. This analysis was restricted to the last two surveys as the first survey undertaken between 1 July 1989 and 30 June 1990 did not have regional information. The second survey was carried out between 1 July 1997 and 30 June 1998 and included over 14,000 people of all ages. From 1 August 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).

In each survey, travel time was assessed by asking respondents to keep a record of the times and places of all their travel over a specified two-day period. Departure and arrival times of each trip leg were recorded, along with trip destination, travel mode and purpose. The use of a two-day travel period minimises respondent burden and reliance on memory, compared to using a week-long period. Shortly after the conclusion of the two-day period, an interviewer questioned each respondent about their travel using the travel record as a memory aid. Interviewers were trained to prompt the respondent to recall any trips (particularly short trips) which may not have been recorded on their memory jogger.

For the second and third surveys, full response rates (i.e., the percentage of eligible households in which all members participated fully in the survey) were 75% and 66% respectively and full and partial response rates (i.e., the percentage of eligible households in which one or more members participated fully in the survey) were 79% and 71% respectively.

Statistical Analysis

The rate of traffic injuries to pedal cyclists resulting in death or hospital inpatient treatment was calculated for each regional group using the equation:

$$\text{Injury rate} = \frac{\text{Total number of cases of cycling injuries per year}}{\text{Total time spent cycling (million hours) per year}}$$

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).[27] 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).[27] 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.[29-31] 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.[30] The annualised numbers of cycling injuries were computed for periods: 1 January 1996 – 31 December 1999 and 1 January 2003 – 31 December 2007 to stabilise small cell sizes.

The annualised per capita and total time spent cycling and time spent travelling as a driver or passenger in a car/van/Ute/SUV were computed from the second (1 July 1997 – 30 June 1998) and third (1 August 2003 – 30 June 2008) travel survey datasets. The data were weighted to account for clustering by household and non-response to the survey.

The rate of traffic injuries per million hours spent cycling was calculated and its association with per capita time spent cycling, per capita time spent travelling in a car and the ratio of time spent cycling to time spent travelling in a car was assessed using log-linear models. Given concerns about the use of ratio variables containing common terms (i.e., time spent cycling),[32] part correlation was undertaken to check for the possibility of spurious associations between the injury rate and per capita time spent cycling and the ratio of time spent cycling to time spent travelling in a car.[33,34]

In addition, for the period 2003-07, the expected numbers of injuries to pedal cyclists in relation to total time spent cycling and total time spent travelling in a car were modelled using the power function $n = b_0 x_1^{b1} x_2^{b2}$ (that has been used in previous research[9,35,36]), where n is the number of injuries to pedal cyclists, x_1 and x_2 are total time spent cycling and total time spent travelling in a car respectively and b_0, b_1 and b_2 are model parameters to be computed.

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[37] (an Abbreviated Injury Scale (AIS)[38,39] score of 3 or more). The mapping to AIS threshold was achieved using the Barell matrix categorisation.[40] 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

Per capita time spent cycling and per capita time spent travelling in a car by region

Annual per capita time spent cycling varied widely across regional groups, 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 (Table 1).

Annual per capita time spent travelling as a driver or passenger in a car/van/Ute/SUV ranged from 213.3 hours in Tasman-Nelson-Marlborough to 318.0 hours in Northland-Auckland during 1997-98 and from 251.6 hours in Taranaki-Manawatu-Wanganui to 344.6 hours in Northland-Auckland during 2003-08.

Rate of traffic injuries to pedal cyclists by region

The rate of traffic injuries, per million hours spent cycling, varied across regional groups, from 11 injuries in Wellington to 33 injuries in Northland-Auckland during 1996-99; and from 12 injuries in Tasman-Nelson-Marlborough to 78 injuries in Northland-Auckland during 2003-07 (Figure 1).

Likewise, the rate of injuries resulting from a collision with a motor vehicle, per million hours spent cycling, ranged from 4 injuries in Wellington to 17 injuries in Northland-Auckland during 1996-99; and from 4 injuries in Tasman-Nelson-Marlborough to 22 injuries in Northland-Auckland during 2003-07.

Associations between the rate of cycling injuries and per capita time spent cycling and per capita time spent travelling in a car

The rate of injuries to pedal cyclists decreased with increasing annual per capita time spent cycling (Table 2, Figure 2). The association did not disappear in part correlation analysis (Table 3). In contrast, the rate increased with increasing per capita time spent travelling in a car particularly during 2003-07.

A significant inverse association was observed between the injury rate and the ratio of time spent cycling to time spent travelling in a car, indicating that the safety benefits of increasing cycling could be attenuated by increasing car use.

Associations between the number of cycling injuries and total time spent cycling and total time spent travelling in a car (2003-07)

The expected number of injuries to pedal cyclists increased with increasing annual total time spent cycling (Table 4, Figure 3); however, this effect occurred at a decreasing rate particularly after controlling for time spent travelling in a car. The increase in total time spent travelling in a car significantly increased the number of cycling injuries whether or not time spent cycling was adjusted.

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 rate of traffic injuries to pedal cyclists and the amount of cycling and travelling as a driver or passenger in a car/van/Ute/SUV 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 risks of cycling injuries and travel exposure variables of interest. However, some limitations should be kept in mind when interpreting the findings. Relatively minor injuries treated in hospital emergency departments, private primary care facilities or in the home 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.[37] While these injuries may not pose a significant threat to life, it cannot be assumed that they will not lead 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.[41,42] However, these inaccuracies are considered to be most likely for death records, particularly among older people.[37,43,44] 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.[37] While it was reassuring to note similar associations when analyses were restricted to serious injuries (as classified by the Barell matrix), we acknowledge that misclassification of injury severity could remain in our analyses.[45] Finally, as this is a cross-sectional analysis, we were not able to distinguish cause from effect. There is also a possibility of spurious associations in analyses involving ratio variables with a common term (time spent cycling);[32] 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 that motorists drive more slowly when they encounter more pedestrians and faster when there are few.[46] 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.[8,47]

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[9,48] 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) particularly after adjusting for the amount of car use. 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.[49] It is likely that increasing traffic volume and speed discourages people to engage in active travel.[50] 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.[51] 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. Many European countries have achieved success in promoting cycling and walking through the "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.[52,53]

While significant barriers exist to implementing such comprehensive measures in many autocentric countries, much could be achieved in the short term. For example, the level of cycling increases substantially in some Australian cities that have invested in bicycle infrastructure.[54] In New Zealand, given that the convenience of car use is one of the main reasons why people don't cycle and walk,[55] car restrictive measures, although often perceived as less important than measures for cycling promotion,[56] deserve particular attention. Possible actions include: congestion charging,[57] Pay-As-You-Drive vehicle insurance,[58] environmental levies on petrol, road closures, car-free zones and car park restrictions. Our analysis shows that if cycle use remains constant at the current level and car use is reduced by 10%, there will be 56 fewer cycling injuries annually nationwide.

Conclusion

In New Zealand, we found 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. Our study has limitations, including a small number of data points, but is consistent with previous research, and implies that the risk profiles of cyclists will worsen if fewer people use a bicycle and more use a car.

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Table 1. Per capita time spent cycling and per capita time spent travelling in a car by region

Regional groups	Per capita time spent cycling per year (hour)		Per capita time spent travelling in a car per year (hour)	
	1997-98	2003-08	1997-98	2003-08
Northland-Auckland	2.66	2.03	318.04	344.56
Waikato-Bay of Plenty	6.55	4.09	289.33	294.15
Gisborne-Hawke's Bay	10.49	6.30	254.41	275.56
Taranaki-Manawatu-Wanganui	9.65	6.85	273.67	251.57
Wellington	9.08	4.55	267.90	301.63
Tasman-Nelson-Marlborough	6.82	13.25	213.33	267.37
Canterbury	12.82	12.82	295.50	294.30
West Coast-Otago-Southland	8.92	7.04	270.96	259.47

Table 2. Associations between the rate of traffic injuries to pedal cyclists and time spent cycling and time spent travelling in a car

Travel exposure variables	Rate of overall injuries			Rate 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 travelling in a car 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 time spent travelling in a car						
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	Rate of overall injuries			Rate 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 time spent travelling in a car						
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

Table 4. Associations between the number of traffic injuries to pedal cyclists and time spent cycling and travelling in a car

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 travelling in a car 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

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

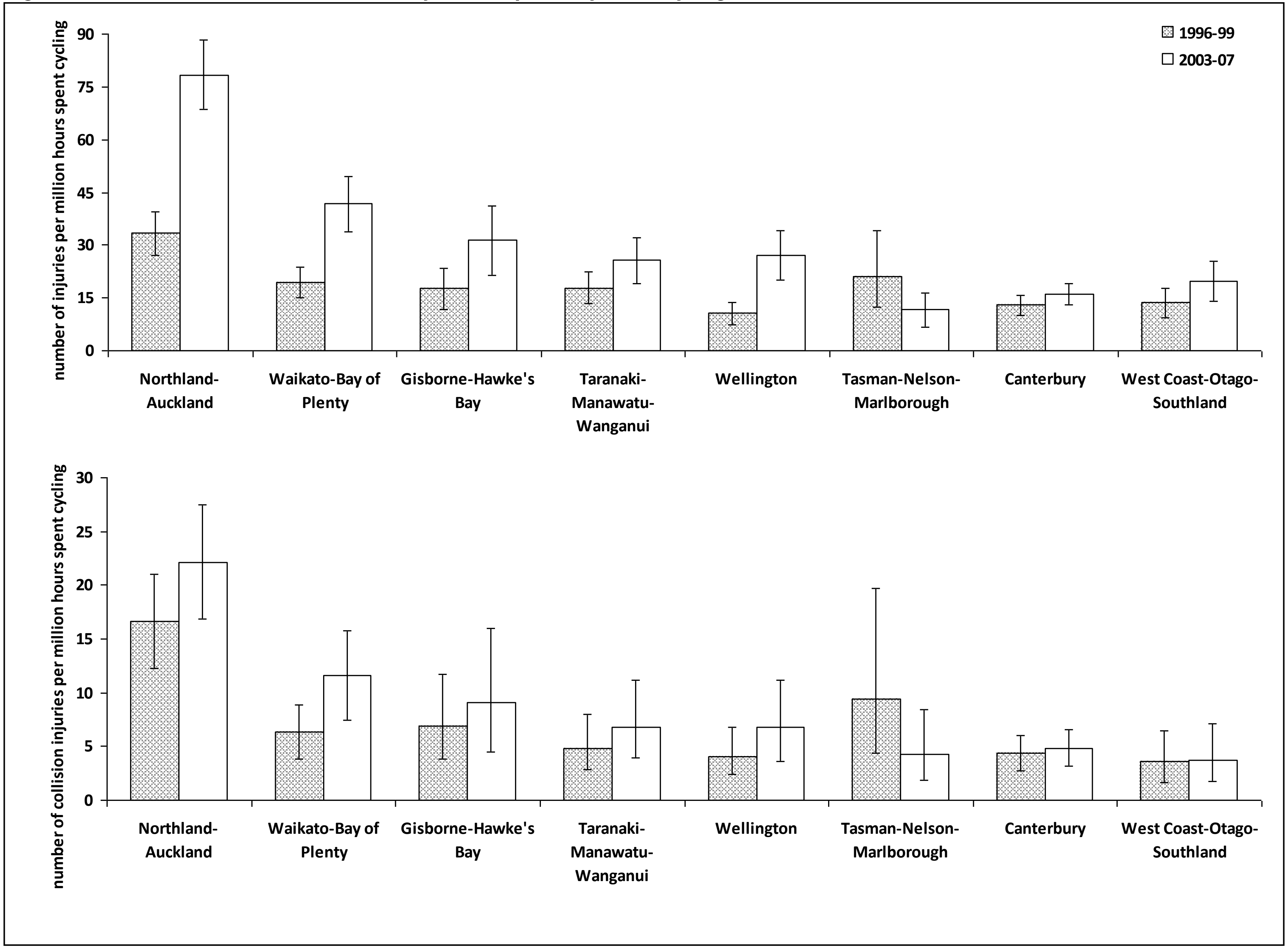
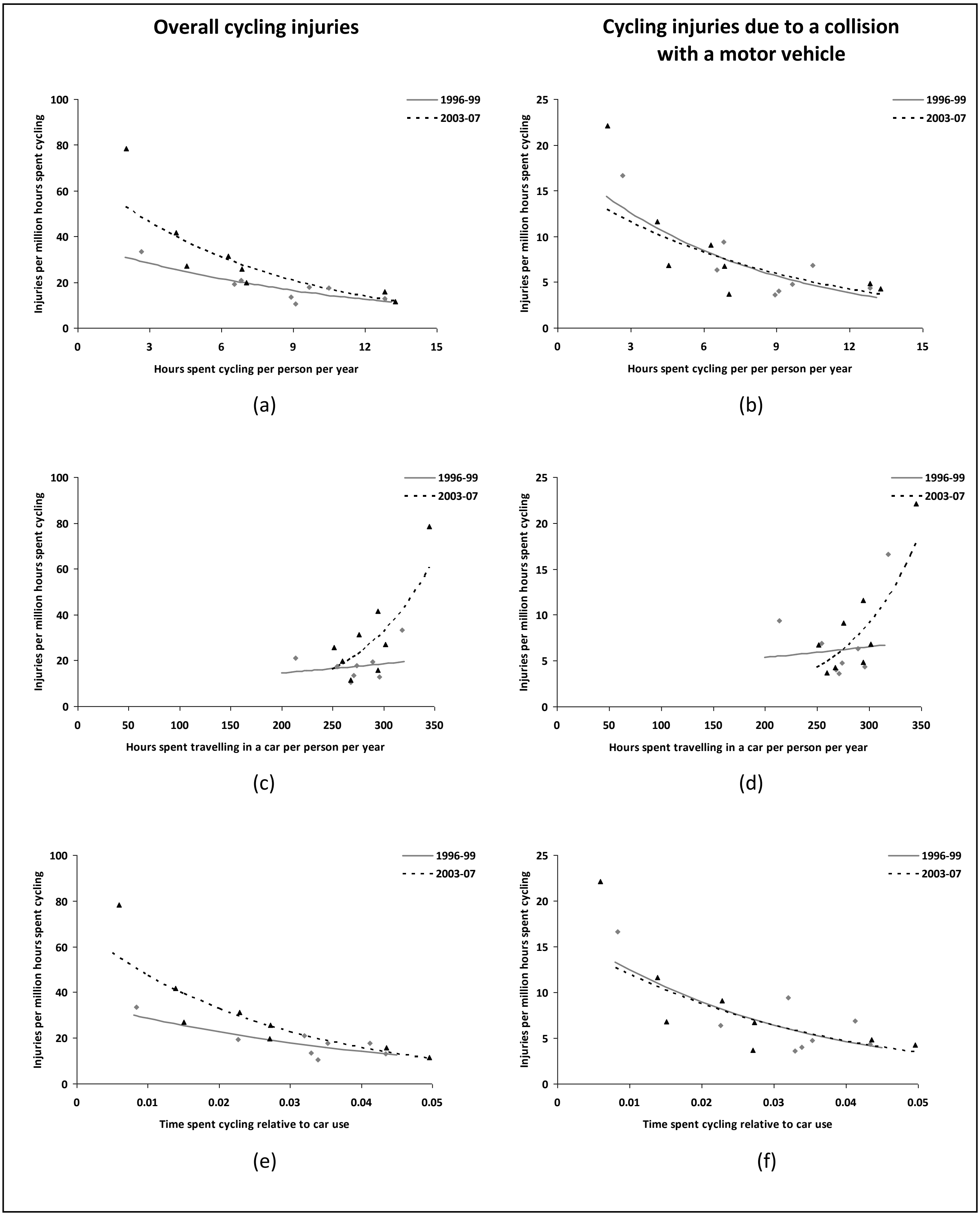
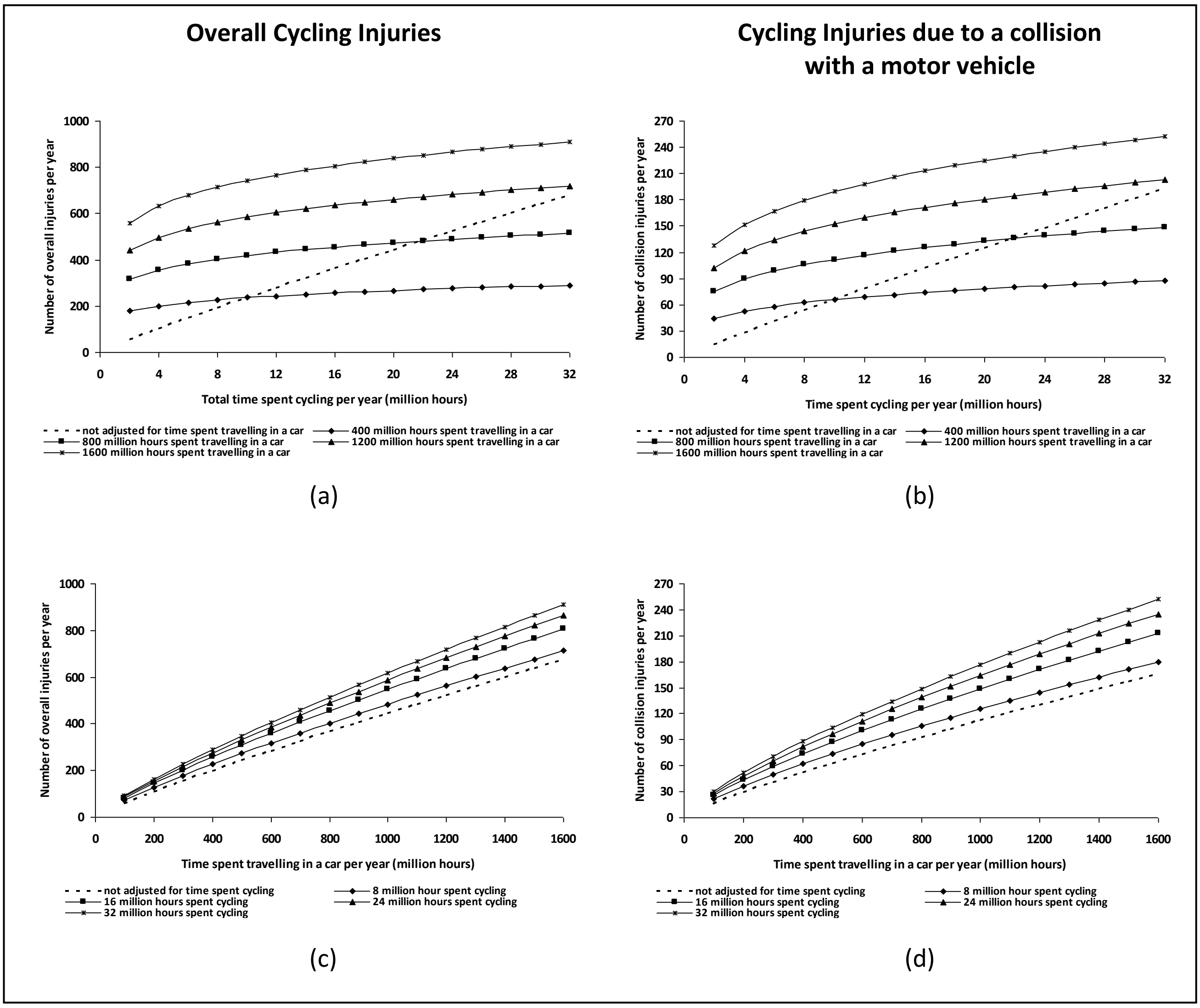


Figure 2. Associations between the rate of traffic injuries to pedal cyclists and per capita time spent cycling and per capita time spent travelling in a car



(a) and (b) – associations between the rate of injuries and per capita time spent cycling
(c) and (d) – associations between the rate of injuries and per capita time spent travelling in a car
(e) and (f) – associations between the rate of injuries and time spent cycling relative to car use

Figure 3. Associations between the number of traffic injuries to pedal cyclists and total time spent cycling and total time spent travelling in a car (2003-07)



(a) and (b) – associations between the number of injuries and total time spent cycling
(c) and (d) – associations between the number of injuries and total time spent travelling in a car