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The impact of compulsory cycle helmet legislation on cyclist head injuries in New South Wales, Australia

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ABSTRACT

The study aimed to assess the effect of compulsory cycle helmet legislation on cyclist head injuries given the ongoing debate in Australia as to the efficacy of this measure at a population level. We used hospital admissions data from New South Wales, Australia, from a 36 month period centred at the time legislation came into effect. Negative binomial regression of hospital admission counts of head and limb injuries to cyclists were performed to identify differential changes in head and limb injury rates at the time of legislation. Interaction terms were included to allow different trends between injury types and pre- and post-law time periods. To avoid the issue of lack of cyclist exposure data, we assumed equal exposures between head and limb injuries which allowed an arbitrary proxy exposure to be used in the model. As a comparison, analyses were also performed for pedestrian data to identify which of the observed effects were specific to cyclists. In general, the models identified a decreasing trend in injury rates prior to legislation, an increasing trend thereafter and a drop in rates at the time legislation was enacted, all of which were thought to represent background effects in transport safety. Head injury rates decreased significantly more than limb injury rates at the time of legislation among cyclists but not among pedestrians. This additional benefit was attributed to compulsory helmet legislation. Despite numerous data limitations, we identified evidence of a positive effect of compulsory cycle helmet legislation on cyclist head injuries at a population level such that repealing the law cannot be justified.

1. Introduction

There are relatively few countries in the world where some or all cyclists are required by law to wear a helmet. Australia was the first country to introduce such legislation and was later followed by New Zealand (NZ) (Attewell et al., 2001). A number of other countries have subsequently introduced similar laws for some or all of the population including Czech Republic, Slovenia, Spain, Malta (Avenoso and Beckmann, 2005), Finland, Sweden, Iceland, Dubai and Japan. Several jurisdictions in Canada and the US have also introduced compulsory helmet laws for at least a sub-section of the population (Macpherson et al., 2002). Extensive research has been published on the impact of compulsory helmet legislation on cyclist head injuries in these countries; however, in the Australian context the debate appears to be ongoing some 20 years after the law was enacted.

Several reviews on the effect of helmet wearing on individual risk of head injury found helmet wearing to be associated with significant reduction in head, brain and facial injury (Henderson, 1995; Thompson and Patterson, 1998; Attewell et al., 2001). The systematic reviews by Attewell et al. (2001) and Thompson and Patterson (1998) used case-control studies; however, Robinson (2006) has suggested that the many observational studies reporting a protective effect associated with helmet wearing may not accurately reflect what occurs at a population level due to unmeasured factors such as risk compensation (Lardelli-Claret et al., 2003), improper helmet wearing and reduced safety in numbers (Robinson, 2005). In 2004, the Cochrane Collaboration published a review of several case-control studies which also found helmet wearing to be efficacious (Thompson et al., 2004), but this work has received some criticism (Curnow, 2005, 2006, 2007; Robinson, 2007), in part due to the majority of the included studies being the work of the review authors.

A number of studies from NZ, Canada and the US found that the introduction of compulsory helmet wearing corresponded to a decline in head injuries to cyclists (Rivara et al., 1994; Povey et al., 1999; Scuffham et al., 2000; Macpherson et al., 2002). In addition, a recent narrative review by the Cochrane Collaboration

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(Macpherson and Spinks, 2008) based on six non-randomised, controlled before and after studies from Canada and the US found that helmet legislation was associated with both increased helmet usage and reduced head injury rates.

On 1 January 1990, the state of Victoria became the first of the Australian states to introduce compulsory helmet legislation and the remaining states and territories followed suit within two years. Some studies in Victoria found evidence of a positive effect of helmet legislation with one study finding a reduction in the proportion of head injuries among injured cyclists (Cameron et al., 1994), while another found a reduction in the count of cyclist head injuries (Carr et al., 1995), both of which attempted to adjust for changes in cyclist numbers and various background confounders. A decrease in cyclist numbers among those aged under 16, predominantly among teenagers, was observed in the years immediately following the legislation in both Victoria and NSW (Walker, 1990, 1991, 1992; Cameron et al., 1992, 1994; Smith and Milthorpe, 1993). It has been argued that the compulsory wearing of helmets has discouraged cycling to the point that the increased burden of disease associated with reduced physical activity outweighs any reduction in the burden of cyclist head injuries (Robinson, 1996; De Jong, 2010). It has also been suggested that reduced numbers of cyclists on the road increases individual risk as motorists are less aware of or willing to accommodate them (Robinson, 2005; Jacobsen, 2003). While the reduction in numbers of teenaged cyclists has been widely cited in the few years immediately after legislation, the opposite was observed among adults and the estimated overall change in cyclist numbers in NSW was close to zero (Walker, 1990, 1991, 1992; Cameron et al., 1992, 1994; Smith and Milthorpe, 1993). It is unknown whether the reductions or increases were temporary or a permanent phenomenon; however, assessments of the legislation's efficacy must take such fluctuations into consideration. A decline in cyclist numbers was only noted in one of the North American studies (Carpenter and Stehr, 2010).

Following the lead of Victoria, the state of New South Wales (NSW) introduced mandatory helmet wearing for cyclists in 1991 at separate times for adults and children: 1 January for those aged 16 and over and 1 July for children aged less than 16. There is scant research into the effect of this legislation in NSW, and certainly no rigorous analyses of population level data. A recent study suggested that any decrease in cyclist head injury in NSW around the time of the law coming into effect was due largely to general improvements in road safety rather than to helmet legislation (Voukelatos and Rissel, 2010); however, the conclusions were undermined by data accuracy issues and has subsequently been retracted (Churches, 2010; Australasian College of Road Safety (ACRS), 2011).

An ideal assessment of the impact of helmet legislation on head injuries among cyclists would require individual level population wide data on cycling exposure and helmet wearing. The lack of such data is a fundamental impediment to generating accurate population level rates of cyclist head injuries and examining their trends in light of compulsory helmet legislation. Previous studies have attempted to deal with this issue by investigating the ratio of head injuries to limb injuries. Povey et al. (1999) analysed the ratio of head injuries to limb fractures among cyclists and non-cyclists, treating limb fractures as a proxy for head injury exposure by assuming that limb fractures were constantly proportional to cyclist exposure. A similar study treats non-head injuries as the proxy by assuming these counts are proportional to person-time exposure (Scuffham et al., 2000). In a NSW based study, Voukelatos and Rissel (2010) used the ratio of head injuries to all arm injuries as a means of avoiding the need for cyclist exposure data. They used the ratio as an indicator of factors which differentially impact one type of injury, but not the other, and they assumed that general fluctuations in cyclist numbers did not affect the ratio. This is an important assumption given the observed reduction in numbers of children cycling in NSW in the years immediately following the introduction of legislation.

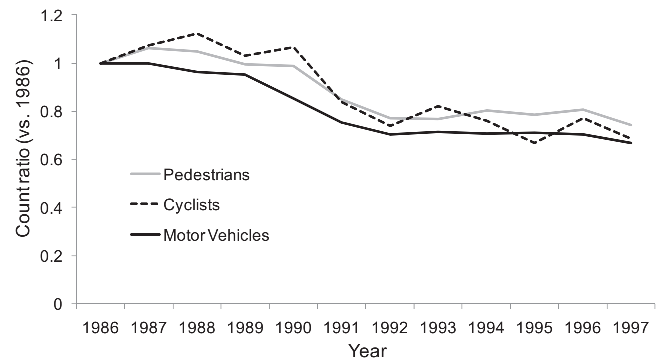

Fig. 1. Annual road casualties for pedestrians, cyclists and motor vehicle occupants: NSW 1986–1997.
Source: (RTA, 2008).

The main focus of this study was to examine trends in the rate of hospitalised head injuries relative to arm injuries among cyclists, focusing in particular on the change in this trend around the time that helmet legislation was introduced. Without exposure data, we assumed the exposures for head and arm injury rates were equal and hence cancelled when we took the relative risk of head to arm injuries. In addition to assuming the equality of rate exposures, our approach also assumed that rates of limb injuries over time would not be affected by helmet legislation and hence any decrease in the ratio around the time of legislation could be attributed to a reduction in head injuries due to mandatory helmet wearing. This assumption implies that helmet legislation is the only factor that could differentially affect head and arm injury rates; however, it is possible that other factors may have such an effect. Road safety improvements, such as the introduction of speed cameras in NSW in 1991 (Australian Transport Safety Bureau, 2004), would be expected to modify vehicle speeds and hence the biomechanics of cyclist traffic accidents, potentially resulting in a differential change to the risk of head and arm injuries. However, the majority of cyclist traffic injuries occur at less than 50 km/h (Simms and Wood, 2009) and hence speed modifying interventions would not be expected to have a marked differential effect on head and arm injury rates. There is no clear evidence of other factors which may affect injury rates differentially.

Many hospitalised cycling accidents occur on roads. Multiple factors influence general safety on NSW roads including enforcement of speed and alcohol limits for motorists as well as campaigns designed to improve the behaviour of road users. Potentially driven by such broader measures, counts of road accidents for pedestrians, motorists and cyclists showed a marked decline approximately between 1989 and 1992 (Fig. 1). In this study, we endeavoured to identify improvements in cyclist head injury rates in NSW in addition to the concurrent trends at the time that compulsory helmet legislation came into effect.

2. Methods

2.1. Data and case definition

The Traffic Accident Database System (TADS) is administered by the NSW Roads and Traffic Authority (RTA) and records all traffic accidents occurring in NSW where a person was killed or injured or where at least one vehicle was towed away (RTA, 2003). Data are available from 1986 onwards. TADS records road user category, including pedal cyclists, for each person involved in an accident,

Table 1
ICD 9-CM codes used for case selection.

		ICD 9-CM code range	5th Character
Operator	Cyclists	E800–E807	3
		E810–E825	6
		E826, E829	1
	Pedestrians	E800–E807	2
		E810–E825	3
		E826, E829	0
Injury type	Head injury	800–804, 850–854 870–873, 830, 910, 918, 920, 921, 925.1, 930–932, 950, 951, 957.0, 959.0	
	Arm injury	810–819, 831–834 840–842, 880–887 912–915, 903, 923, 927, 955, 959.2–959.5	
	Leg injury	820–828, 835–838 843–845, 890–897 904.0–904.8, 924.0–924.5 916, 917, 928, 956, 959.6, 959.7	

whether a person was injured or killed, and whether a helmet was worn. The database does not record any details about the type of injuries sustained.

The NSW Admitted Patients Data Collection (APDC) records all hospital inpatient admissions which have occurred in NSW since the financial year 1988–1989. In the APDC, external causes and diagnoses were classified exclusively using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD 9-CM) system until the end of 1996–1997. Data used in this analysis were entirely from this period. For the purpose of this study, head injury admissions were defined as all injuries to the skull, face and scalp; arm injuries were defined as all injuries to the shoulder girdle, arm, wrist and hand; and leg injuries were defined as those affecting the hip, leg and foot. Admissions involving head and limb injuries to cyclists were defined using the ICD 9-CM external cause and diagnosis codes shown in Table 1. Records where the separation mode was either a type change separation or a transfer to another hospital were excluded to avoid multiple counting of the same period of care. Prior to 1993–1994 the APDC was not a census of all hospital admissions in NSW. To account for this a temporal sampling factor exists in the dataset which gives additional weight to admissions in non-census years so that counts approximately represent those expected from census data.

A number of ICD 9-CM codes combine head and neck injuries (920, 957.0, 959.0, 910.8) in a single code, hence there may be some neck injuries included among the head injury cases. However, based on the three years of APDC data where multiple ICD coding version were used, this appears to affect less than 2% of all annual head injury admissions, or approximately 10 cases per year.

2.2. Statistical methods

It has been suggested that the transition to high rates of compliance with the helmet law may have taken some 6–12 months from the date that the legislation came into effect (Voukelatos and Rissel, 2010). Using data from TADS, the proportion of cyclists involved in accidents who wore a helmet was plotted for 18 months before and after the legislation date in order to approximately assess the lag in compliance after the compulsory helmet legislation came into effect.

Log-linear regression of admission counts was performed with three covariates: TIME, INJURY and LAW. The variable INJURY took on a value of one for a head injury and zero for a limb injury to estimate the ratio of head injury rates to arm injury rates. If cyclist exposure data was available this ratio could be expressed as

$$\frac{x_H/n_H}{x_L/n_L}$$

where x_H and n_H are the count and exposure for cyclist head injuries; x_L and n_L are the count and exposure for cyclist limb injuries. Due to the lack of exposure data, by assuming exposures to be equal for head and limb injury rates, specifically that $n_H = n_L = n$, then the rate ratio can be expressed as a ratio of counts, i.e.,

$$\frac{x_H/n}{x_L/n} = \frac{x_H}{x_L}$$

Hence, by including equal arbitrary exposures for head and limb injuries in a log-linear count model, this assumption allows the coefficient of INJURY to be interpreted as the ratio of head to limb injury rates. It makes intuitive sense that a cyclist would be equally exposed to both head and limb injuries for the person time spent cycling. However, the common use of person counts as a proxy exposure can introduce bias into rate estimation, necessitating the explicit statement of this assumption. It should also be noted exposures do not need to be equal for valid comparisons between head and limb injuries, but should be at least proportional over the study period (i.e., n_H/n_L = constant).

TIME represents monthly intervals defined using the date of admission and was treated as a continuous covariate. Due to the absence of admission date in the first year of the APDC, 1988–1989, the duration of pre-law data available for adults was 18 months. Eighteen months of pre- and post-law data was therefore included for both age groups resulting in a 36 month analysis period centred on the date that the legislation came into effect and taking into account the different dates for adults and children. Thus for adults the period was from July 1989 to June 1992 and for children from January 1990 to December 1992. The variable LAW was included as a binary variable which had a value of zero prior to legislation and one thereafter.

A previous study identified seasonal patterns in cyclist injury counts (Carr et al., 1995). A plot of monthly counts for 10 years of aggregated data showed counts in January to be over 80% higher than counts in June. Including both adults and children in the same model with time centred at the date of legislation introduced two distinct seasonal patterns which were out of phase with each other. This made it non-trivial to adjust for seasonal trends through the inclusion of a seasonal factor in the model. An alternative solution, similar to that used by Bernat et al. (2004), was to seasonally adjust the monthly counts of hospital admissions separately for adults and children using the X11 method (Shiskin et al., 1967). The adjusted counts were then combined and analysed in a single regression model.

Due to the presence of moderate overdispersion, negative binomial regression was performed with the three covariates described as well as all possible interaction terms. Due to likely differences in the distribution of age and sex among cyclists compared to the population, these variables were excluded to avoid the potentially significant bias they may have introduced. The time specific NSW population was used as the arbitrary exposure (Australian Bureau of Statistics, 2008), with exposures for head and arm injuries being equal in each time interval. Linear interpolation was used to generate monthly population counts from the half yearly population estimates. There is evidence that cyclist numbers did not follow the same trend over time as the population (Walker, 1990, 1991, 1992; Smith and Milthorpe, 1993). Despite this assumption potentially creating bias in estimates of time trends, it will impact head and arm injury rates equivalently and so will not affect inferences about this relationship. As a comparison, the total number of cyclist accidents in TADS was used as an alternative proxy exposure. Although this does not capture off-road cycle accidents, it is more likely to be parallel to the true trend in cyclist exposure than the population count. The TADS data was also expected to reflect seasonal trends, so this sensitivity analysis did not adjust the original injury counts for seasonality.

With time being treated as a continuous variable, a saturated model was used of the form:

$$\log(\text{count}) = \beta_0 + \beta_1\,\text{TIME} + \beta_2\,\text{INJURY} + \beta_3\,\text{LAW} + \beta_4\,\text{TIME} \times \text{INJURY} + \beta_5\,\text{TIME} \times \text{LAW} + \beta_6\,\text{INJURY} \times \text{LAW} + \beta_7\,\text{TIME} \times \text{INJURY} \times \text{LAW} + \log(\text{exposure})$$

This saturated model was chosen to capture all temporal changes in injury rates in order to fully account for background trends and legislation specific effects. INJURY represents head injury rates as compared to limb injury rates, while LAW estimates overall post-law rates compared to the pre-law period. Pre-law trends in arm injuries rates are estimated by TIME and the interaction between TIME and INJURY allows a different trend for head injury rates. The interaction between TIME and LAW indicates any difference in overall post-law trend compared to the pre-law trend and is expected to capture the background trends represented in Fig. 1. The three way interaction term allows the rate of change of head injury rates compared to arm injury rates to differ between pre- and post-law periods. Finally, the interaction between INJURY and LAW estimates any differential changes in head injuries compared to arm injuries with the change in helmet wearing legislation. If head injuries decreased by more than limb injuries among cyclists at the time of legislation, the INJURY × LAW interaction would represent this as a significant negative estimate. If the estimate is non-negative, this may be interpreted as no evidence for a legislation attributable benefit.

While it may seem reasonable to assume that all cyclists are exposed to both head and arm injuries, to assess the assumption that these exposures are equal, models were built using arm and leg injuries as separate comparison groups. Also given the uncertainty around the assumption that differential changes in counts of head and arm injuries around 1991 are attributable to helmet wearing as a result of the legislation, we ran the same analysis for pedestrians to assess whether any such differential changes were unique to cyclists or not. Throughout the analysis period there were five diagnosis fields in the APDC. Using all diagnosis fields compared to using only the principal field to define head and limb injuries resulted in a greater increase in counts of arm and leg injuries than head injuries. This suggested that head injuries are more likely to be coded in the principal diagnosis field while limb injuries are more likely to appear in subsequent fields. Due to this potential bias associated with using the principal diagnosis only, analyses were performed by defining head and limb injury cases using all five diagnosis fields.

The overall fit of the models was assessed by comparing the Pearson chi-square statistic to the chi-square distribution with degrees of freedom given by the total number of parameters minus the number of parameters estimated (Dobson and Barnett, 2008).

3. Results

During the 36 month analysis period there were 2154 hospital admissions involving a head injury incurred while cycling, along with 2221 arm injuries and 1196 leg injuries. Over 75% of these admissions involved males and around 60% affected children aged less than 16. Sixty percent of the head injuries occurred prior to helmet legislation compared to 52% of arm injuries and 55% of leg injuries. Around 82% of cycling-related admissions were coded as E826.1, the description for which is 'Pedal cycle accident–pedal cyclist'. Of the remaining cases, 17% were classified as traffic accidents and 5% as non-traffic accidents.

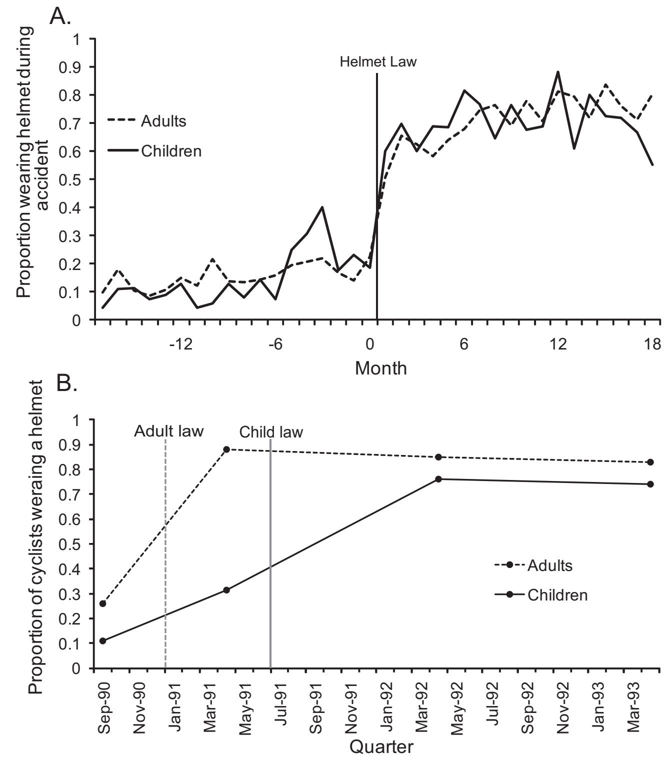

Fig. 2. A. Proportion of cyclists wearing a helmet among those involved in an accident 18 months pre- and post-cycle helmet legislation. B. Observed proportion of cyclists wearing helmets pre and post cycle helmet legislation.
Source: (Walker, 1990, 1991, 1992; Smith and Milthorpe, 1993).

In Fig. 2A, helmet wearing among those involved in traffic accidents appears to have increased from approximately 20% to more than 60% among children and over 70% for adults within two months of the legislation coming into effect. A small additional increase may also have occurred subsequent to the initial rapid change. The actual rates of helmet wearing may have been higher than those shown since around 20% of TADS records each year were missing this information. The post-law rates of helmet wearing approximately concur with the RTA surveys in Fig. 2B, in which helmet wearing rates over 70% among children and more than 80% for adults were observed in the first survey following legislation and remained close to this level in subsequent surveys.

3.1. Regression models

With the exception of pedestrian arm injuries, all estimated trends in injury rates showed a moderate decrease in the pre-law period, with mean annual percentage decreases between 4.5% and 23.6% per year (Fig. 3). In the post-law period, the trend was reversed, with all injury rates, except pedestrian leg injuries, increasing by between 3.5% and 21.2% per year on average. A further feature common to the four models was a negative untransformed estimate of LAW which indicated that injury rates overall were lower following helmet legislation (Table 2).

For both cyclist-related models, the untransformed estimate of the interaction between INJURY and LAW was significant and negative (Table 2), indicating an additional decrease in head injury rates compared to arm injury rates following the introduction of legislation. This is represented by a downward 'step' noticeable in Fig. 4A and C. Of the two pedestrian related models, one showed a smaller negative, but non-significant estimate, while the other

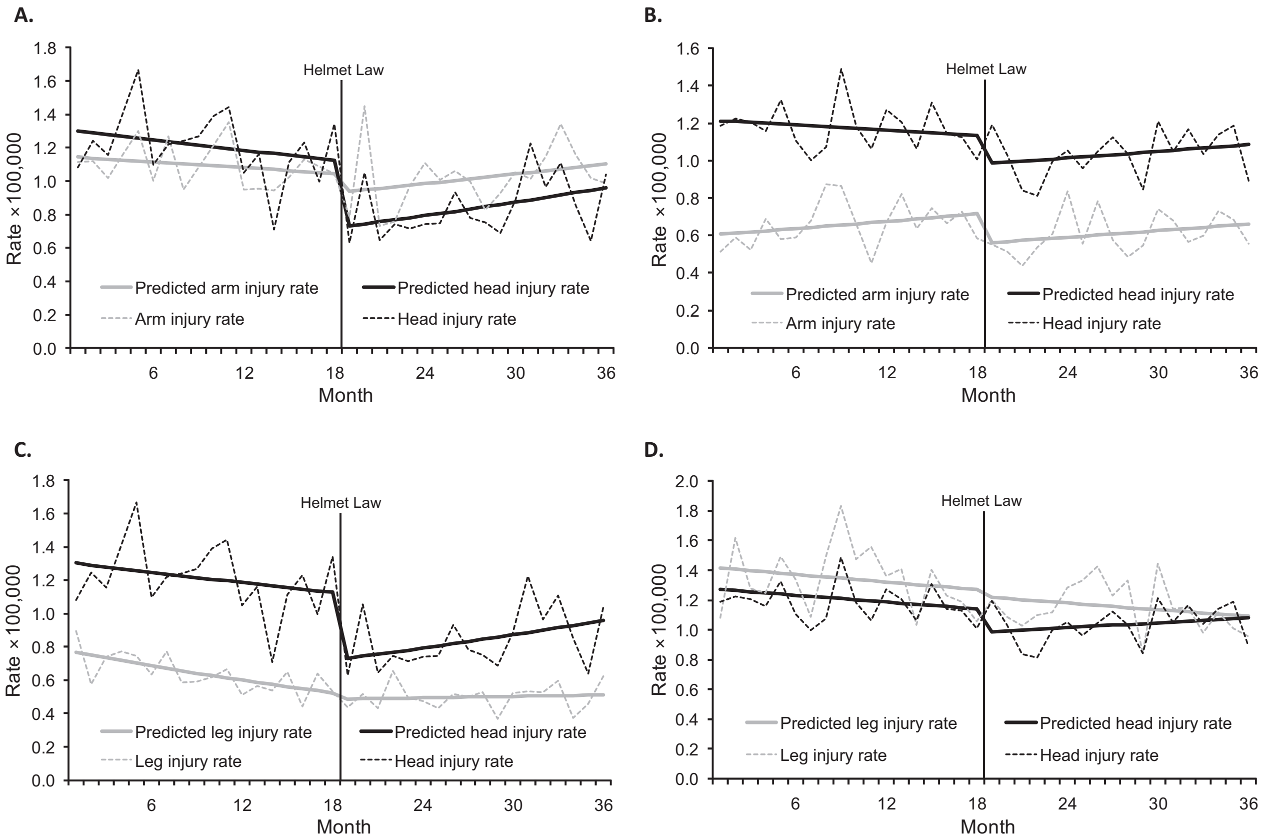

Fig. 3. Cyclist and pedestrian injury rates and predicted values for 18 months prior and 18 months post helmet legislation. (A) Cyclists – head vs. arm injury rates. (B) Pedestrians – head vs. arm injury rates. (C) Cyclists – head vs. leg injury rates. (D) Pedestrians – head vs. leg injury rates.

found a non-significant positive value. As shown by the smaller 'steps' in opposing directions in Fig. 4B and D.

Both models using arm injury rates as the comparison showed approximately parallel trends in the post-law period while the models using leg injury rates as a comparison exhibited contrasting trends. With the inclusion of three or five years of post-law data these trends tended to approach stability. With 18 months of post-law data, trends ranged from −7.5% to 21.2% per year, whereas with five years of data the range of trends was −0.6 to 9.2%. For all four models, a test of the Pearson's chi-square statistic was non-significant at the 0.05 level indicating a reasonable fit.

4. Discussion

In this study we have endeavoured to identify the effect of mandatory helmet legislation on head injury rates as distinct from other road safety interventions in the period of interest. We accounted for background trends due to any concurrent safety factors and addressed a range of data limitations which have previously posed a considerable impediment to assessing the impact of cycle helmet legislation in the NSW context. A range of models were built in order to mitigate these limitations and some key effects were observed.

Table 2
Untransformed negative binomial model estimates for cyclists and pedestrians using 18 months pre-law and 18 months post-law data.

Comparison injury		Cyclists			Pedestrians		
	Variable	Estimate	95% CI	*p*-Value	Estimate	95% CI	*p*-Value
Arm	TIME	−0.005	−0.019, 0.009	0.45	0.010	−0.004, 0.023	0.16
	INJURY	0.072	−0.128, 0.272	0.48	0.457	0.288, 0.626	<0.001
	LAW	−0.112	−0.318, 0.093	0.28	−0.250	−0.451, −0.048	0.02
	TIME × LAW	0.015	−0.005, 0.034	0.14	0.000	−0.020, 0.019	0.99
	INJURY × LAW	−0.322	−0.618, −0.027	0.03	0.106	−0.144, 0.356	0.41
	TIME × INJURY	−0.003	−0.022, 0.016	0.74	−0.014	−0.03, 0.003	0.11
	TIME × INJURY × LAW	0.010	−0.018, 0.038	0.50	0.010	−0.014, 0.034	0.43
	Pearson χ^2 statistic (df)	73.97	64	0.18	74.83	64	0.17
Leg	TIME	−0.022	−0.039, −0.006	0.01	−0.006	−0.017, 0.005	0.25
	INJURY	0.772	0.553, 0.991	<0.001	−0.110	−0.277, 0.057	0.19
	LAW	−0.064	−0.318, 0.191	0.62	−0.036	−0.201, 0.130	0.67
	TIME × LAW	0.025	0.001, 0.049	0.04	0.000	−0.016, 0.016	1.00
	INJURY × LAW	−0.371	−0.696, −0.046	0.03	−0.108	−0.350, 0.134	0.38
	TIME × INJURY	0.014	−0.007, 0.034	0.18	0.003	−0.013, 0.019	0.75
	TIME × INJURY × LAW	−0.001	−0.032, 0.03	0.95	0.010	−0.014, 0.033	0.42
	Pearson χ^2 statstic (df)	65.38	64	0.43	70.4	64	0.27

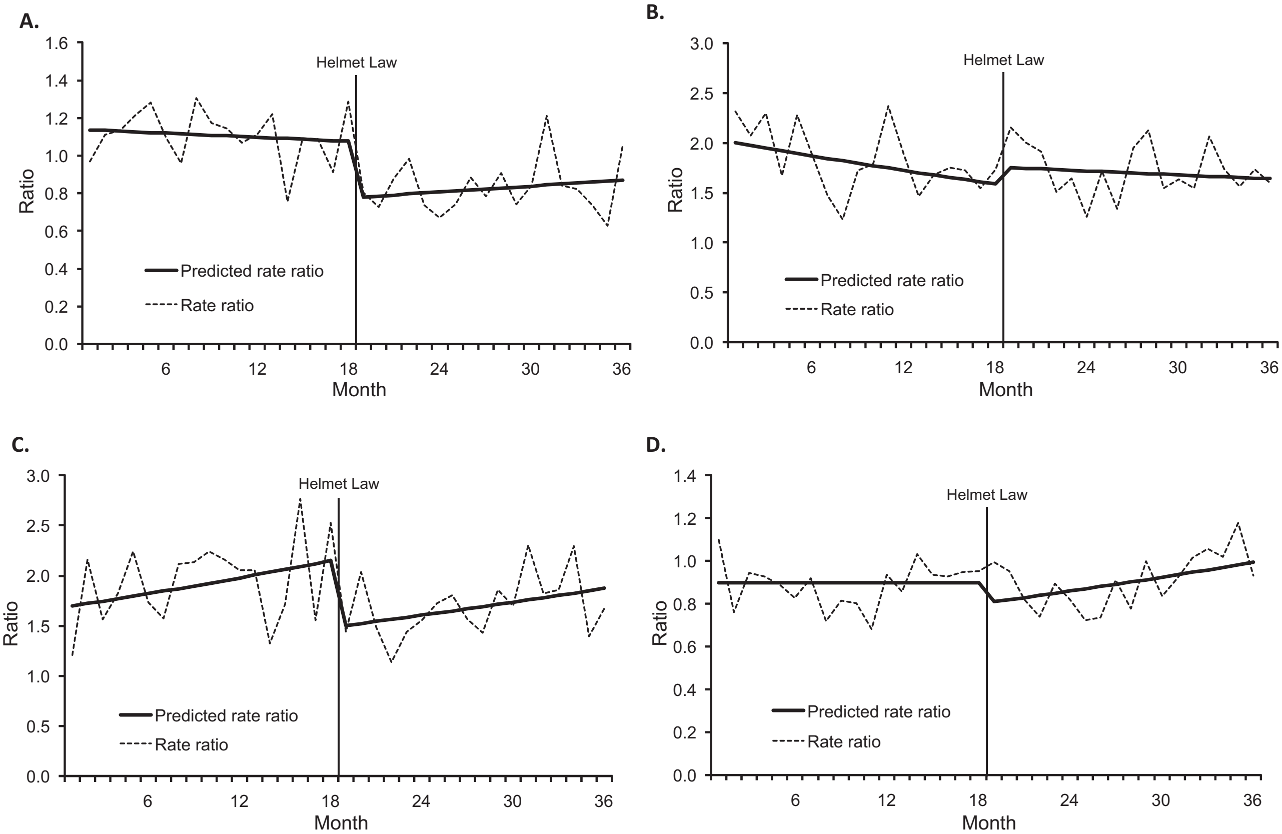

Fig. 4. Cyclist and pedestrian rate ratios and predicted values for 18 months prior and 18 months post helmet legislation. (A) Cyclists – head vs. arm injury rates. (B) Pedestrians – head vs. arm injury rates. (C) Cyclists – head vs. leg injury rates. (D) Pedestrians – head vs. leg injury rates.

A number of features were largely common in all models such as a generally decreasing trend in rates prior to legislation with an increasing trend thereafter, as well as an overall decrease in rates following the introduction of helmet wearing legislation. The commonality of these features suggests that they are representative of background changes in injury risk and are not specific to any of the groups considered. These observed trends approximately agree with those in Fig. 1 and discussed in Section 1. Part of the pre-law decreasing trend and the decrease at the time of legislation may have been driven by broader road safety improvements related to enforcement of motor vehicle laws and promotion of safer road use. In the case of cyclists, the overall post-law decrease in rates may also be due partly to a reduction in numbers of young cyclists in the immediate post law period while the proxy exposure did not correspondingly decrease. Such an impact on cycling numbers is not a positive effect of the legislation; however, it is not known whether this decrease was maintained in the long term. Given that legislation was in place before today's young riders were born, enforced helmet wearing may no longer have a deterrent effect in this age group. Further research is required to elucidate any ongoing effects more clearly.

Among cyclists, the decrease in rates at the time of legislation was significantly greater for head injuries than arm or leg injuries as shown by the estimates of the INJURY × LAW interaction in Table 2. This effect was not observed to be significant or consistent among pedestrians, which suggests that in addition to the overall decrease in cyclist injury rates around the time of legislation there was a further decline in head injury rates. Given the attempts of this study to address all sources of uncertainty as far as possible, it is reasonable to assume that this differential decrease is attributable to compulsory helmet legislation. The legislation attributable decrease was estimated as 25% or 29% depending on whether arm or leg injuries were the comparison; however, these figures should be treated with some caution due to the limitations discussed below. Among studies that also observed a decrease in cyclist head injury rates, a Canadian study found a 23% reduction in the odds of head injury when a helmet was worn (Macpherson et al., 2002). A Victorian study reported a 39.5% state wide reduction based on time series modelling which attempted to account for any changes in overall cyclist numbers related to the legislation (Carr et al., 1995). An assessment of legislation in California, USA, identified an 18.2% reduction in traumatic brain injury independent of compliance and changes in bicycle use (Lee et al., 2005). Although differences in study design make comparison difficult, the magnitude of these estimates is not dissimilar from our findings.

The tendency towards stability in post-law trends with the inclusion of additional years of data suggests that either 18 months is not sufficient follow up time to accurately detect trends or that the trends shown represent temporally localised changes that did not persist beyond the analysis period. Based on the original analysis there is some evidence that the initial improvement in head injury rates diminished over the 18 months following legislation as shown by the increasing post-law head to limb injury ratios in Fig. 4. Alternatively, the longer term post-law trends being closer to parallel for head and limb injury rates (equivalent to a post-law horizontal line in Fig. 4A and C) supports the idea that the legislation attributable improvement was maintained.

This study has a number of limitations associated with both the data and the analysis methods. The limited amount of data available prior to legislation may have reduced the power of our analysis to detect genuine trends. This is specific to hospital data in NSW and suggests the value of conducting a similar analysis in a jurisdiction with more pre-law data.

Lack of population level exposure and helmet wearing data for cyclists meant that several assumptions were necessary for an analysis to be possible. We have assumed that the additional decrease in head injuries at the time of legislation was attributable to the legislation; however, it is not possible to infer causality with certainty without having helmet wearing data on all cyclists. Although we have attempted to allow for background trends, there may be additional unmeasured factors at play that have contributed to the observed effects. For example, changes in proportions of commuter and recreational cyclists, changes in behaviour of cyclists and other road users, or improved cycling infrastructure. Also the contribution of factors such as risk compensation and safety in numbers has not been incorporated in this study. A large scale survey of cyclists would be required to examine such effects.

We avoided the need for cycling exposure data by assuming equal exposures between head and limb injuries. The difference in results when arm or leg injuries were used as a comparison suggests that this assumption may not necessarily be the case. Further, the population was used as an arbitrary exposure which was equal for head and limb injuries in each given time period. It is possible; however, that cyclist numbers and person-time exposure has varied in a different way over time compared to the population. This increases the uncertainty of the time related estimates, but is less likely to affect comparisons between head and limb injury rates. To test this, we used the total count of cycle traffic accidents from TADS as the proxy exposure in an effort to mimic the total number of cyclists at each time point. The results produced similar estimates for time related variables, which suggests that any bias associated with using population counts as a proxy exposure may be minimal.

The seasonal adjustment process resulted in non-integer counts, which is theoretically problematic for regression based on a discrete distribution such as the negative binomial distribution used in this study. However, the analysis was also performed without seasonal adjustment using the original integer counts, and similar although more significant results were obtained. Despite the limitation of using non-integer values, the results have not overstated the effect of helmet legislation.

The uncertainty around the analysis in the NSW context strongly suggests conducting a similar study using data from a jurisdiction in which more pre-legislation data exists. This would also add to the number of statistically rigorous assessments of helmet legislation in the Australian context, of which there are currently few. While helmet legislation appears to play an important role in the reduction of cyclist head injuries, further improvements in cyclist safety in general may be gained from a broader focus. Cyclist safety is a complex issue driven by a range of factors. Cycling in Australia has changed with a considerable increase in recreational road cycling and mountain biking in recent years. Additional research into the diverse and changing risk profiles among these cycling subgroups would facilitate further safety improvements.

Of the Australian jurisdictions, NSW has the second highest rate of injury among commuting cyclists (Lehman et al., 2008), while a NSW based survey identified considerable intolerance and animosity between cyclists and motorists (AMR Interactive, 2009). This suggests that increased volume and quality of cycling infrastructure could improve safety, particularly for cycling commuters, through reduced competition for road space with motor vehicles. It also indicates a need to promote responsible sharing of roads where adequate cycling infrastructure does not exist. Considerable funding has become available in NSW for safe and connected cycling networks and construction of infrastructure has commenced, the effect of which should be increasingly apparent in coming years (NSW BikePlan, 2010). Also, a non-government organisation has recently funded a campaign to encourage motorists to allow cyclists sufficient space on the road, although there have been no government campaigns to this end in recent years. In addition to the safety improvement effects of these interventions, they would also likely encourage more people to cycle for both recreation and transport (Winters et al., 2010).

Despite numerous data limitations, we have identified evidence of a positive effect of compulsory cycle helmet legislation on cyclist head injuries at a population level such that repealing the law cannot be justified. We have also developed an analysis which may effectively be applied to similar data from other jurisdictions.

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