The effectiveness of helmets in bicycle collisions with motor vehicles: a case-control study

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ABSTRACT

There has been an ongoing debate in Australia and internationally regarding the effectiveness of bicycle helmets in preventing head injury. This study aims to examine the effectiveness of bicycle helmets in preventing head injury amongst cyclists in crashes involving motor vehicles, and to assess the impact of 'risky cycling behaviour' among helmeted and unhelmeted cyclists. This analysis involved a retrospective, case-control study using linked police-reported road crash, hospital admission and mortality data in New South Wales (NSW), Australia during 2001 to 2009.

The study population was cyclist casualties who were involved in a collision with a motor vehicle. Cases were those that sustained a head injury and were admitted to hospital. Controls were those admitted to hospital who did not sustain a head injury, or those not admitted to hospital. Standard multiple variable logistic regression modelling was conducted, with multinomial outcomes of injury severity.

There were 6,745 cyclist collisions with motor vehicles where helmet use was known. Helmet use was associated with reduced risk of head injury in bicycle collisions with motor vehicles of up to 74%, and the more severe the injury considered, the greater the reduction. This was also found to be true for particular head injuries such as skull fractures, intracranial injury and open head wounds. Around one half of children and adolescents less than 19 years were not wearing a helmet, an issue that needs to be addressed in light of the demonstrated effectiveness of helmets. Non-helmeted cyclists were more likely to display risky riding behaviour, however, were less likely to cycle in risky areas; the net result of which was that they were more likely to be involved in more severe crashes.

KEYWORDS: bicycles, helmets, head injury, brain injury, motor vehicle collisions

INTRODUCTION

Mechanisms of active travel such as cycling, whether solely for sport and recreation or as a means of transport, can contribute towards population-level health benefits, however cycling also poses a risk of injury. Many of the serious and fatal injuries involve cyclists sustaining head injuries, and one of the mechanisms proposed to reduce the severity of head injury has been helmets (Cummings et al. 2006).

In Australia, the state of Victoria was one of the first regions worldwide to introduce mandatory helmet legislation for cyclists on public roadways in 1990, with the remaining Australian states introducing mandatory helmet legislation over the following two years. To date, there has been ongoing debate regarding the effectiveness of cycling helmets in preventing head injuries (Curnow 2003, Thompson et al. 1999, Walter et al. 2011).

Prior studies that have examined this issue have been population-based cohorts (Povey et al 1999, Scuffham and Langley 1997, Scuffham et al 2000, Tin Tin et al 2010, Walter et al. 2011) and case-control studies (Amoros et al. 2012, Hanson et al. 2003, Heng et al. 2006, Maimaris et al. 1994, McDermott et al. 1993, Spaite et al. 1991, Thomas et al. 1994, Thompson et al. 1989, Thompson et al. 1996). While the case-control studies have typically shown that helmets reduce the odds of head injury to some extent, they have had conflicting findings as to the magnitude of the reduction experienced. This is largely due to different study inclusion criteria, particularly in relation to the type of injury experienced (i.e. head, neck, or facial injury) and its severity, and the type of helmet worn (i.e. hard or soft shell).

Case-control studies are a valid method to examine whether helmets worn during cycling are effective in preventing head injury among cyclists (Cummings et al, 2006). Yet some of the previous case-control studies have had limitations. For example: (i) not all were population-based, with some studies only including a sample of trauma centres and/or hospitals, limiting the generalisability of the results; (ii) some studies only had a relatively small number of cases, which precluded any in-depth examination of some risk factors, such as age, or the examination of different types of head injuries and their severity; (iii) not all studies included deaths that occurred outside the hospital system, which would underestimate injury severity estimates; (iv) not all studies examined the severity of the injury sustained by the cyclist; and (v) only one case-control study examined factors directly related to ‘risky riding behaviour’ in their analysis of alcohol intoxication (Heng et al. 2006). The limitations of previous case-control studies need to be addressed in order to determine whether bicycle helmets are an effective means of preventing head injury amongst cyclists in collisions with motor vehicles, or whether helmets are able to contribute towards a decrease in the severity of the injury experienced.

Risk compensation and homeostasis theories assume that an individual will change their risk taking behaviour based on how they perceive the level of actual risk (Lardelli-Claret et al. 2003). In relation to cycling, it has been argued that helmeted cyclists may be more cautious and therefore may be more likely to ride more carefully and/or in safer locations (for example, in parks, playgrounds, cycle paths) than unhelmeted cyclists, thus the cautious behaviour could account for the reduction in the experience of head injury in helmeted cyclists (Robinson 2007). On the other hand, it has also been argued that helmeted cyclists could ride more recklessly as they feel more protected and as a result they are more likely to be involved in crashes (Thompson et al.1996). The impact of risky cycling behaviour needs further investigation.

This study aims to use a case-control methodology to examine the effectiveness of bicycle helmets in preventing head injury amongst cyclists in crashes involving motor vehicles in New South Wales (NSW), Australia during 2001 to 2009, and to assess the impact of ‘risky cycling behaviour’ among helmeted and unhelmeted cyclists. While there have been many case-control studies assessing the protective effect of helmets, the novel aspects of the present study include the use of linked data, the inclusion of many possibly confounding variables determined from police crash reports, the restriction to only motor vehicle collisions on public roadways, the inclusion of cyclist casualties that did not require hospital treatment and the use of multinomial outcome logistic regression models to model the severity of the head injuries sustained. A number of limitations identified in previous case-control studies are addressed.

METHODS

This is a retrospective case-control study using linked police-reported road crash, hospital admission and mortality data in NSW.

Data collections

The Admitted Patient Data Collection (APDC) includes information on all inpatient admissions from all public and private hospitals, private day procedures, and public psychiatric hospitals in NSW. The APDC contains information on patient demographics, source of referral, diagnoses, external cause(s), separation type and clinical procedures. Diagnoses and external cause codes are classified using the International Classification of Diseases, 10^{th} Revision, Australian Modification (ICD-10-AM) (National Centre for Classification in Health, 2006). The NSW Registry of Births, Deaths and Marriages (RBDM) records information on all deaths in NSW and contains information on basic demographics and the date of death.

The CrashLink data collection contains information on all police-reported road traffic crashes where a person was unintentionally fatally or non-fatally injured, or at least one motor vehicle was towed away and the incident occurred on a public road in NSW. Information pertaining to the crash and conditions at the incident site, the traffic unit or vehicle, and the vehicle controller and any casualties resulting from the crash are recorded. Each individual is identified as being non-injured, injured or killed (died within 30 days). Data were extracted for pedal cyclists involved in collisions with motor vehicles that were injured or killed, and are termed 'cyclist casualties'. Data for cyclists that were non-injured were excluded, since these incidents are rarely reported to police and the group is thus difficult to identify and may suffer from selection bias. Data were extracted from all data collections from 1 January 2001 to 31 December 2009.

Data linkage

The APDC and the RBDM data collections were linked to CrashLink by the Centre for Health Record Linkage (CHeReL). The CHeReL uses identifying information (e.g. name, address, date of birth, gender) to create a person project number (PPN) for each unique person identified in the linkage process. The record linkage used probabilistic methods and was conducted using *ChoiceMaker* software (ChoiceMaker Technologies, 2012). A successful link with CrashLink was defined as when the PPN matched in both data collections, and the admission date in the APDC was on the same day or the next day as the crash date, or the death date in the RBDM was on the same day or within 30 days of the crash date.

Injury identification

Head injuries were defined as those that affected the skull and brain only. Specific injury categories considered include skull fractures (i.e. vault, base and other or multiple skull fractures; ICD-10-AM: S02.0, S02.1, S02.7, S02.8, S02.9), intracranial injury (i.e. concussive, diffuse or focal brain injury; ICD-10-AM: S06), open wounds (of the scalp; ICD-10-AM: S01.0, S01.83), and head injury generally (i.e. skull fractures, intracranial injury, open wounds and multiple or other head injury; ICD-10-AM: S01.0, S01.83, S02.0, S02.1, S02.7, S02.8, S02.9, S06, S09.7, S09.8, S09.9).

Injuries to body regions other than the head were identified by ICD-10-AM injury codes S10 – T89 excluding the head injury codes previously mentioned. There were 42 cyclist fatalities resulting from collisions with motor vehicles during the study period, and in 24 (57.1%) cases no injury information could be obtained. These 24 cases were excluded from the study population.

Injury severity

Injury severity was calculated directly from the ICD-10 injury codes, using the probability of survival for each individual code, termed a Survival Risk Ratio (SRR). The SRR for an ICD code is the proportion of survivors among all cases with that ICD-coded injury. The procedure has been compared with the Abbreviated Injury Scale (AIS) and has proved equivalent or superior in assessing mortality (Davie et al 2008, Stephenson et al 2004). In a separate study using the APDC for all land transport trauma, the hospital records for 109,843 individuals were used to generate SRRs for all ICD-10 injury codes during 2001 to 2007 (Bambach et al 2012). These data represent a census of all land transport trauma in NSW during the period, and for each ICD injury (ICD_i) the SRR was calculated from Equation 1. The SRRs for the head injury codes relevant to the present study are presented in Appendix A. The mean SRRs for the AIS categories of serious (AIS 3) and severe (AIS 4) were identified as 0.965 and 0.854, respectively (AAAM, 2005). These values are used in the present study for identifying serious and severe injury using the ICD approach to maintain consistency with the well-established AIS approach.

$$SRR_{ICD_i} = \frac{Number\ of\ individuals\ with\ injury\ ICD_i\ that\ survived}{Total\ number\ of\ individuals\ with\ injury\ ICD_i} \tag{1}$$

The head injury ICD classifications for each injured cyclist were assigned SRRs, and a minimum SRR (i.e. the most severe injury) was identified in each of the head injury categories. The minimum SRR was assigned an injury severity according to Table 1. The cyclists that were identified as being injured by police, but were not admitted to hospital (i.e., did not have a linked APDC record), were classified as ‘possible minor injury’. Information on the type of injury sustained is not available in the police crash records, thus the ‘non-hospital admitted’ cyclists may not have sustained a head injury. Alternatively, the cyclist may have sustained a head injury, however did not require admission to hospital for treatment. Such injuries may have been treated in an emergency department, by a general practitioner or other health professional, or may have been self-treated. Additionally, the SRRs were calculated for each cyclist excluding any head injuries. Cyclists with one or more non-head SRRs less than 0.965 were classified as being ‘seriously injured other than the head’.

Case-control study design

The study population was cyclist casualties (police-designated as injured or killed) resulting from a police-reported collision with a motor vehicle. The cases were those that were admitted to hospital and sustained a head injury (SRR≤1). The cases were disaggregated into cyclists that sustained one or more skull fracture(s), intracranial injury(s) or open wound(s). Within each head injury type, the cases were further disaggregated into cyclists for whom the most severe injury was moderate, serious or severe (Table 1).

The controls were those admitted to hospital who did not sustain a head injury, or those not admitted to hospital (sustained no head injury or a minor head injury), termed ‘Control 1 - no head injury casualties’. A second control group consisted of a subset of Control group 1 that was admitted to hospital but did not sustain a head injury, termed ‘Control 2 - no head injury hospitalisations’. Ideally, a control group should also contain cyclists that were involved in a collision with a motor vehicle that were not injured; however, no population-based data sources were available to identify these cyclists, and they were not able to be considered in this study.

Statistical analysis

Standard multiple variable logistic regression modelling was conducted using SAS v9.2 (SAS Institute, 2010). All available human, vehicle and environmental characteristics of the crashes that might be associated with the outcome of injury were considered as variables in the logistic regression models. These included: speed limit as a polytomous variable with four levels; collision vehicle as a polytomous variable with four levels; age as a polytomous variable with six levels; and dichotomous variables of metropolitan (or rural), intersection (or not), curve (or not), highway/freeway (or not), sealed road (or not), dry road (or not), daytime (or not), equipment failure (or not), cyclist blood alcohol concentration (BAC) of over 0.05 (0.05% by volume) (or not), male (or female), cyclist riding on/from the footpath (or the roadway), operator (or pillion), the cyclist disobeyed a traffic control (or not), seriously injured other than the head (or not) and whether the cyclist wore a helmet (or not). Reference cell coding was used for polytomous variables, where the reference groups were 0-50km/h (for the speed limit), collision with a car/van/utility (for the collision vehicle) and age group of 50+ years. The youngest age group was aggregated at 12 years, as it is legal for children under 12 years to cycle on the footpath in NSW (it is also legal for adult guardians of children less than 12 years to cycle on the footpath in accompaniment).

The four injury severity outcome categories (possible minor, moderate, serious or severe injury) meet the criteria for a multinomial distribution; i.e. each outcome falls into one of four categories, each outcome is independent of the other outcomes, given the covariates the probability of each category is fixed, and the probabilities sum to unity. Therefore, multinomial regression with the logit link was a logical choice to model the data. Parameter estimates were determined from the method of maximum likelihood, and odds ratios and 95% confidence intervals were determined from the estimates and standard errors. The statistical significance of estimates was assessed at the 0.05 level. Relative risk (%) is not equivalent to the odds ratio determined from logistic regression; however, Zhang and Yu (1998) have shown that if the outcome occurs in less than 10% of the unexposed population considered, then the difference between the two is negligible. The relative risk values were calculated from the odds ratios in such cases.

The method of purposeful selection was used in order to select the variables for the multinomial logistic regression model (Bursac et al 2008). Initially, a univariate logistic regression model was developed for each variable to determine if it should be included in the full model, based on its statistical significance. The full model was then developed, and each included variable was considered for retention in the model based on its significance. Each non-significant variable (including variables that were not included and variables that were not retained) was then included in the full model and assessed for potential confounding with any of the other variables. Where confounding occurred, it was retained despite its non-significance. As recommended by Bursac et al (2008), the inclusion and retention criteria were set at 0.25 and 0.1, respectively, and confounding was assessed at the 15% change (in parameter estimate) level. All possible linear and higher order combinations of variables were assessed for inclusion at the 0.1 level. Each model was assessed for goodness-of-fit (using the likelihood ratio, LR, and the Hosmer and Lemeshow statistic, HL) and discrimination (using the area under the receiver operating characteristics curve, AUC).

RESULTS

Linkage results

The overall linkage rate of police-reported individuals to individuals admitted to hospital was 70.7%. That is, 70.7% of hospitalised cyclists (resulting from motor vehicle collisions) were police-reported and included in the present study population. The linkage rates are calculated for several variables available in the APDC in Appendix B, where factors affecting linkage are identified.

Descriptive results

The total number of police-reported cyclist casualties resulting from collisions with motor vehicles in NSW between 2001 and 2009 was 8,293. Excluding those individuals where helmet use was unknown (18.7%) resulted in a study population of 6,745 cyclists. Of the total 6,745 cyclist casualties, 1,859 (27.6%) were admitted to hospital, including 1,220 (18.1%) without any head injuries and 639 (9.5%) with one or more head injuries. Of the 639 cyclists with head injuries, 274 (42.9%) sustained intracranial injury(s), 118 (18.5%) sustained skull fracture(s) and 92 (14.4%) sustained open wound(s), with the remaining (24.2%) sustaining multiple or other head injury(s). For the hospitalised cyclists that sustained injuries, upper and lower extremity injuries dominated all injuries (54.2% and 52.6%, respectively), while head injury was the most frequently sustained serious injury (13.8%) (Figure 1).

Helmet use and crash characteristics

The overall helmet wearing rate amongst the 6,745 cyclists was 75.4%, and the proportions of helmeted and non-helmeted cyclists for all crash variables considered are presented in Table 2. A forest plot of unadjusted (univariate) associations of each variable with helmet use is presented in Figure 2. Compared to unhelmeted cyclists, helmeted cyclists were statistically significantly more likely to be older, female, cycling in higher speed zones, less likely to sustain serious injuries other than the head, less likely to disobey a traffic control, less likely to have a BAC over 0.05, less likely to be riding on the footpath, more likely to be riding on a highway or freeway and more likely to be riding during the day.

Crash characteristics of cases and controls

The proportions of case and control groups for all crash variables considered are presented in Table 3. Compared with the ‘no head injury cyclist casualties’ (Control 1), head injured cyclists were: less frequently wearing a helmet (44.1-58.4% compared with 77.2%), more frequently cycling in higher speed zones (17.8-20.6% compared with 9.9% in 70km/h or greater zones), more frequently collided with large vehicles (17.8-23.7% compared with 12.2%), more frequently disobeyed a traffic control (9.4-11.9% compared with 4.3%), more frequently cycling with a BAC greater than 0.05 (5.5-8.8% compared with 2.4%) and rode less frequently on the footpath (13.9-18.6% compared with 18.6%). The age group with the highest proportions of skull fractures and intracranial injuries was the 13 to 19 years group (25.4% and 24.1% respectively). The cyclists with skull fracture had the highest proportion of individuals with serious injury other than the head (52.5%). Nearly half of the head injured cyclists sustained serious or severe head injury (30.5% and 12.1% respectively), while for skull fracture, intracranial injury and open wounds the proportions of serious injury were 75.4%, 25.9% and 0% respectively, and for severe injury were 11.0%, 25.9% and 10.9% respectively.

Helmet use and severity of head injury

For the outcomes of head injury, skull fracture, intracranial injury and open wounds, conditional upon a cyclist casualty being in a police-reported collision with a motor vehicle, and assuming all other variables remain the same, the odds ratios for wearing a helmet compared with not are presented in Table 4. Due to small case counts (Table 3), some injury severity groups were aggregated. Compared with possible minor head injury, cyclists not wearing a helmet had 1.98 (95% CI 1.52 – 2.57), 2.65 (95% CI 1.87 – 3.75) and 3.89 (95% CI 2.23 – 6.76) times higher odds of sustaining moderate, serious or severe head injury, respectively. Compared with possible minor skull fracture, cyclists not wearing a helmet had 2.29 (95% CI 0.68 – 7.68) and 4.61 (95% CI 2.80 – 7.55) times higher odds of sustaining moderate or serious/severe skull fracture, respectively. Compared with possible minor intracranial injury, cyclists not wearing a helmet had 1.60 (95% CI 1.04 – 2.45), 2.81 (95% CI 1.58 – 5.00) and 3.52 (95% CI 1.98 – 6.29) times higher odds of sustaining moderate, serious or severe intracranial injury, respectively. Compared with possible minor open wounds, cyclists not wearing a helmet had 5.00 (95% CI 3.03 – 8.21) times higher odds of sustaining moderate/serious/severe open wounds. All odds ratios were statistically significant at the 0.05 level, except for moderate skull fracture (p=0.171). Control group 2 of no head injury hospitalisations resulted in generally similar, but slightly smaller odds. The model diagnostics for the logistic regression results in Table 4 are presented in Table 5. The models generally showed good discrimination and fit, with those using Control group 1 typically performing marginally better than those using Control group 2.

The full results for the multiple variable logistic regression model with multinomial outcomes for head injury are presented in Table 6. Non-significant and non-confounding variables were excluded. No variable interactions were found to be significant, and interactions between gender and age were assessed prior to the removal of gender from the model due to non-significance. Due to the large volume of data, only the results for all head injury are provided; however, the results for the other injury models were generally similar. Statistically significant odds ratios for increased head injury severity included: increased odds of 1.9-2.5 times for 100-110km/h speed zones compared with 0-50 speed zones; increased odds of 1.8-1.9 times for large collision vehicles compared to cars;

increased odds of 6.4-13.3 times when a serious injury was sustained other than in the head region; increased odds of 1.7-3.2 times when the cyclist disobeyed a traffic control; increased odds of 3.5-4.1 times for cyclists with a BAC over 0.05; and increased odds of 2.0-2.9 times for cyclists that were riding on the roadway compared with the footpath.

Risky cycling behaviour and helmet use

Non-helmeted cyclists were more likely to display imprudent cycling behaviour, including disobeying a traffic control (9.4% compared with 3.3%) and cycling with a BAC greater than 0.05 (7.2% compared with 1.7%) (Table 2). However, non-helmeted cyclists were more likely cycling on the footpath (34.4% compared with 12.9%) and in speed zones of 50km/h or less (56.9% compared with 50.0%), and less likely cycling on highways or freeways (8.3% compared with 12.6%). Overall, non-helmeted cyclists were more likely to be seriously injured in body regions other than the head (9.5% compared with 7.3%). All of these results were statistically significant at the 0.05 level (Figure 2).

DISCUSSION

This is one of the first case-control studies examining cyclists, helmet use and head injury severity that have used linked police-reported crash data, hospital admission and mortality data. This study found that the odds of sustaining a head injury increased 1.98 to 3.89 times for cyclists that were not wearing a helmet, depending on the severity of injury considered. Similar odds were determined for the particular injuries of skull fracture (2.29 to 4.61 times), intracranial injury (1.60 to 3.52 times) and open wounds (5.00 times). Likewise, other case-control studies found that non-helmet use had increased odds of head injury amongst cyclists, with increased odds of 1.4-2.9 (Amoros et al 2011), 1.2-2.8 (Hanson et al 2003), 3.3 (Maimaris et al 1994), 1.6 (McDermott et al 1993), 2.0 (Thomas et al 1994), 3.8 (Thompson et al 1989) and 3.2 (Thompson et al 1996). The present results were also similar with regards to brain injury (Thomas et al 1994, Thompson et al 1989, Thompson et al 1996), and a number of other studies of head and brain injury discussed in a meta-analysis conducted by Attewell et al (2001).

The injury outcomes considered occurred in less than 10% of the population, that is the proportions of individuals that sustained any head injury or any particular head injury (skull fracture, intracranial injury or open head wound) were less than 10% of the total number of individuals (for Control group 1 of no head injury casualty controls). Thus the odds ratios in Table 4 may be approximately expressed as relative risk. Accordingly, the risk of moderate, serious or severe head injury was found to be reduced by 49.4% (95% CI 34.1% – 61.2%), 62.2% (95% CI 46.4% – 73.3%) and 74.3% (95% CI 55.2% – 85.2%), respectively, with helmet use. The reduction in risk of up to 74.3% is similar to an early study of Thompson et al (1989) which found a reduction of 75%. This suggests that despite changes in helmet design and roadway environment, helmets remain as effective as they were more than two decades ago. These results are in contrast to the conclusions of Elvik's (2011) reanalysis of Attewell et al (2001), where it was reported that the reduction in the risk of head injury from helmet use has declined over time from 75% to around 55%.

Some authors have argued that cycle helmets are not effective in collisions with motor vehicles, due to the fact that they are designed for less severe impacts, such as single cyclist falls (McCarthy 1992, Hillman 1993). As the current study only examined cyclist and motor vehicle collisions, which in other case-control studies had represented a low proportion of all crashes (21.2% in Amoros et al 2011, 7.4% in Hanson et al 2003, 45% in Heng et al 2006, 27.6% in Maimaris et al 1994, 15.2% in McDermott et al 1993, 9.1% in Thomas et al 1994, 10.5% in Thompson et al 1989 and 15.3% in Thompson et al 1996), the protective effect of helmet wearing is applicable to motor vehicle collisions. In fact, prior studies have shown that motor vehicle collisions with cyclists, compared to non-collisions, result in: an increase in the overall severity of injury (Heng et al 2006); an increase in the odds of serious injury by 4.6 times (Rivara et al 1997); an increase in the odds of upper head injury (Thomas et al 1994); an increase in the odds of head injury by 2.95 times (Maimaris 1994), 1.81 times (Hansen et al 2003) and 1.68 times (Amoros et al 2012); and an increase in the odds of serious head injury (AIS 3+) by 2.48 times (Amoros et al 2012).

Aside from helmet use, a number of other characteristics were found to be significantly associated with head injury in cyclist collisions with motor vehicles. Increased odds of head injury were associated with higher speed zones and the size of the collision vehicle. This is likely to result from the increased kinetic energy of the collision vehicle, and it is well established that increased collision energy is associated with increased injury severity outcome. Similarly, the result for increased odds of head injury with increased severity of injury in regions other than the head, is also generally indicative of the severity of the crash. Likewise, Amoros et al (2012) found that cyclists who had an Injury Severity Score (ISS) (i.e. AIS based injury severity scores) in excess of 16 had 12 times higher odds of sustaining a serious (AIS 3+) head injury. The present result for odds of increased injury severity with increased age is also a well established physiological result.

Increased odds of head injury were found in the present study with cyclist alcohol use (BAC over 0.05) and disobeying a traffic control. Alcohol use has previously been reported as being associated with increased injury severity and/or risk of head injury (Anderson and Bunketorp 2002, Olkkonen and Honkanen 1990, Spaite et al 1995). It has also been observed, as in the present study, that alcohol-affected cyclists are less likely to wear a helmet (Anderson and Bunketorp 2002, Heng et al 2006). It is possible that the association of a traffic infraction with increased odds of head injury might result from generally more risky cycling behaviour.

It has been argued that cyclists who wear helmets may differ from those that do not, such as riding in 'safer' locations, which are likely to expose them to less severe crash modes and thus introduce an element of confounding into case-control studies. DiGuisseppi et al (1989) and Robinson (2007) have suggested that helmet wearers are more likely to ride in parks, playgrounds or bicycle paths than city streets, thus are less exposed to the most severe crash mode which is a collision with a motor vehicle. This limitation is not relevant to the present study, since only crashes involving collisions with motor vehicles were included.

Prior studies of cyclist use of helmets and head injury have not regularly examined proxies for risky cycling behaviour, which could introduce an element of confounding into case-control studies. It has been suggested that helmet wearers are more likely to obey traffic laws, wear fluorescent clothing and use lights at night (Robinson 2007, Farris et al, 1997, McGuire and Smith 2000), which may result in them being involved in less severe crashes than non-helmet wearers. Indeed, Lardelli-Claret et al (2003) found that committing a traffic violation was significantly associated with a lower frequency of helmet use. In the present study, non-helmeted cyclists were significantly more likely to display risky cycling behaviour (i.e. disobeying a traffic control and cycling with a BAC greater than 0.05). However, they were also more likely to be cycling in areas that would expose them to less severe crashes (i.e. on footpaths and not on highways/freeways or in higher speed zones). Overall, non-helmeted cyclists were more likely to be seriously injured in body regions other than the head. These results suggest that cycling behaviour is slightly different between helmeted and non-helmeted cyclists, and using serious injury other than that to the head as a proxy for overall crash severity, the two groups were in slightly different severity crashes. Spaite et al (1991) also found that non-helmeted cyclists in collisions with motor vehicles were more likely to be seriously injured other than in the head region; however, the effect was more substantial than that found in the present study. McDermott et al (1993) found the converse to be true, where helmeted casualties had more frequent body injuries and higher non-head injury severity.

In the current study, cycling on the footpath prior to the collision with a motor vehicle was associated with decreased odds of head injury. This suggests that separating cyclists and motor vehicles has a positive effect on injury reduction, and supports the development of cycling infrastructure such as cycle lanes and pathways. The results also identified young cyclists (less than 19 years) as both less frequently wearing helmets and more frequently sustaining head injuries (including all types of particular head injuries considered). Notably, 47.2% of 0 to 12 year-olds and 50.3% of 13 to 19 year-olds were non-helmeted, compared with 14.6% of the 30 to 39 year-olds. This suggests that helmet non-use amongst young cyclists riding on (or adjacent to) NSW roadways should be targeted in awareness raising and enforcement campaigns. This is not the first time that helmet non-use amongst children and adolescents in Australia has been highlighted as requiring preventive action (Boufous et al 2011).

Prior case-control studies have had some limitations, particularly in relation to age adjustment, small injury counts for brain injury and the treatment of diffuse brain injury. Robinson (2007) noted that only three age categories were considered in the Thompson et al (1989) case-control study, and that this may have been inadequate for age adjustment. In the present study, six age categories were used. Robinson (2007) also noted that the majority of head injuries in previous case-control studies were not brain injuries, and the small count of n=90 AIS2+ brain injuries (Thompson et al 1989, 1996) resulted in the odds ratios for brain injury reported in the Cochrane review (Thompson et al 1999) being inconclusive. In the present study, a substantial n=274 individuals with intracranial injury were identified.

Curnow (2003) assessed the meta-analysis of case-control studies performed by Attewell et al (2001), and concluded that since the case-control studies did not specifically identify diffuse axonal injury (DAI), there was not sufficient evidence to suggest that helmets were effective in reducing brain injury. That is, while focal injury associated with skull damage would be reduced with a helmet, this might mask the helmets failure to reduce DAI. In the present study, focal brain injury (ICD-10-AM: S06.3) constituted only 13% of individuals with intracranial injury, while concussive injury (concussion or loss of consciousness; ICD-10-AM: S06.0) constituted the majority (79%). Only 9 individuals sustained an open skull fracture communicating with an intracranial injury. Unfortunately, DAI is not specifically identified in the ICD-10-AM classification system, however concussive injury was assessed independently and the odds ratios for helmet use were 0.535 (p=0.003) and 0.262 (p<0.0001) for moderate and serious/severe concussive injury, respectively (compared with Control group 1 of no head injury casualty controls). Only 8 individuals sustained loss of consciousness on a time scale satisfying one of the requirements for the diagnosis of DAI (more than six hours, AAAM 2005), thus in the current study DAI could have occurred in no more than 8 cases of brain injury (2.9%). Therefore in the present study, the possibility of DAI was at most a very minor proportion of brain injury, and not specifically addressing it is thus unlikely to affect the conclusions regarding the protective effect of helmets in preventing intracranial injury.

There are several limitations of the current study. This study identified cyclist and motor vehicle crashes using police-reported data; however, not all crashes are reported to police. Therefore, police-reported data are a sample of all crashes and could suffer from selection bias. However, using the police-reported data had advantages in that many additional variables that are not routinely recorded in hospital data collections were able to be included as potential confounders, and cyclists that were involved in a casualty crash, but did not require hospital treatment, could be included in the control group. There were 1,548 cyclist casualties that were excluded from the study due to their helmet use being unknown. In order to assess the effect of this exclusion, these casualties were added to the study population and helmet use was coded as a polytomous variable (yes/no/unknown). Compared with possible minor head injury, cyclists wearing a helmet had odds of 0.512 (95% CI 0.395-0.655, $p<0.0001$), 0.382 (95% CI 0.272-0.537, $p<0.0001$) and 0.272 (95% CI 0.158-0.468, $p<0.0001$) for sustaining moderate, serious or severe head injury, respectively, compared with not wearing a helmet. Comparing these results to those in Table 4 indicates that the exclusion of the unknown cases results in slightly non-conservative estimates of the protective effect of helmets.

The selection of the control group should ideally include all cyclists that collided with a motor vehicle (including those that were not injured). While the present study included cyclists that required hospital treatment, and cyclists that did not but were identified by police as sustaining an injury of some sort, non-injured cyclists were excluded. This control group is valid if the helmet-wearing prevalence is the same as that for all cyclists, which is a realistic assumption (Marshall 2008). However, those cyclists that were involved in a collision and sustained a head impact, and their use of a helmet protected their head from injury, were excluded. This leads to an underestimation of the size of the control group and thus the protective effect of helmets. A similar issue concerns the two different control groups considered. The exclusion of cyclists that did not require hospital treatment in the no head injury hospitalisations Control group 2, led to a small underestimation of the protective effect of helmets compared with Control group 1. This result supports the extensive reliance on the use of hospitalisation control groups in previous case-control studies, and confirms that the effect is both small and conservative.

The linkage rate was found to be 70.7%, which indicates that the police-reported cyclist collisions with motor vehicles used in the present study are a sample of all such crashes that required hospital treatment in NSW over the period considered. However it was shown in Appendix B that these data may be considered applicable to the wider population of bicycle-motor vehicle collisions in NSW, and that the sample was slightly more likely to contain cyclists with more serious injury outcomes. The latter may result in the estimates for the protective effect of helmets in the present study being conservative. It is noted that the linkage rate for all cyclists in the APDC hospital admissions data collection was 22.2%, which indicates that police-reporting of cyclist crashes is generally very low. The substantial difference between the police-reporting rate for all cyclists (22.2%) and for cyclists in motor vehicle collisions (70.7%) indicates that cyclists that collided with a motor vehicle were much more likely to report the event to police, compared with those that collided with fixed objects/pedestrians/other cyclists or those in a non-collision crash. This might be related to the fact that in NSW, insurance claims related to motor vehicle damage and/or personal injury resulting from a motor vehicle collision, require the incident to be reported to police.

Other limitations were that some of the variables used relied on the varying and uncertain skills of police officers that attended the scene and may involve errors. There may be discrepancies between the manner in which different police jurisdictions record different particulars of a crash. The designation of injured (casualty) in the police-reported crash data is subjective and not clearly defined, and is based on the discretion of the reporting police officer. The statistical method used determines associations with injury; however, it does not conclusively imply causality. There may be additional variables that are associated with injury that were not available in the data, of which notable examples are the speeds of the cyclist and collision vehicle. The minimum SRR (most severe injury) was used for each individual in each injury category, which ignores the effects of multiple injuries that may have occurred in each category. This results in a conservative estimate of the overall injury severity in each category, which may result in the estimates for the protective effect of helmets to be conservative in the present study. The probabilistic linkage method is not without possible linkage errors; however, false positives and false negatives were estimated to be 0.4% and 0.5%, respectively. Examination of the external causes coded in the hospital records indicated that of those that linked to the police-reported crash records; 86% were coded as cyclists in collisions with motor vehicles, a further 8% were coded as cyclists in other types of crashes, and the remaining 6% were coded as other/unknown road users. It was assumed that the police-reported crash record was likely to be more accurate in the recording of the road user category and crash type, since this is the principal role of the police record (while the principal role of the hospital record is the recording of injuries and medical procedures), thus all hospital records linked to the police-reported crash records were retained.

A number of studies have demonstrated different helmet efficacy for soft-shelled and hard-shelled helmets (Hansen et al 2003, Rivara et al 1997, Thompson et al 1996). In the present study, such a determination could not be made, since these data are not recorded in CrashLink. However, the majority of cyclist helmets in the Australian market have been shown to be of the micro-shell types (McIntosh et al 1998), which consist of a very thin shell incorporated during the moulding process. Additionally, data on whether the helmet came off during the collision was not available, which may result in an underestimation of the protective effect of helmets (McDermott et al 1993).

CONCLUSIONS

This case-control study of 6,745 cyclist casualties resulting from collisions with motor vehicles has indicated that helmet use is significantly associated with reduced risk of head injury by up to 74%. This includes reductions in risk of up to 78% for skull fracture, 72% for intracranial injury, 74% for concussive injury and 80% for open head wounds. The magnitude of the reduction in risk increased when increased severity of injury was considered. DAI constituted a very minor proportion of brain injury. The study confirms the results of many previous case-control studies, while addressing many of the limitations of such studies. Most notably, limitations relating to confounding by unknown variables have been addressed with the use of police-reported crash data.

Helmeted and non-helmeted cyclists were statistically significantly different with regards to cycling behaviour, where non-helmeted cyclists were more likely to display risky riding behaviour, while less likely to cycle in risky areas. While the net result was that they were more likely to be involved in more severe crashes, this difference was small. The overall helmet wearing rate was 75.4%, while only about half of children and adolescents less than 19 years were wearing a helmet. Given the large protective effect of helmets demonstrated in the present study, this issue should be addressed with preventative action.

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FIGURES

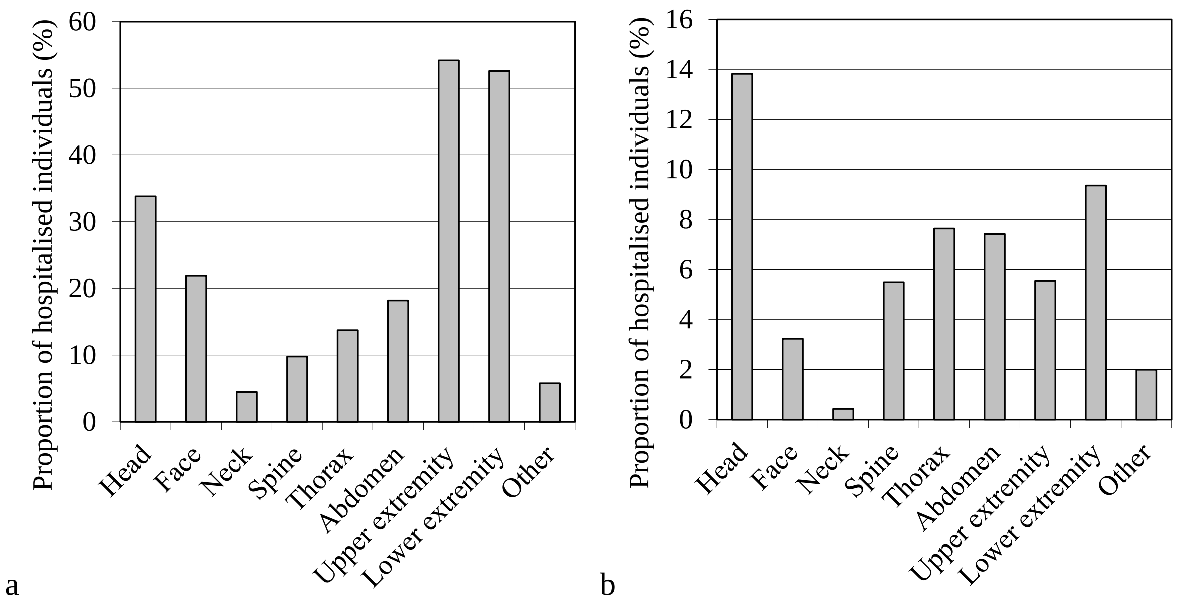

Figure 1: Proportions of hospitalised cyclists (n=1,859) that sustained at least one injury to particular body regions following a collision with a motor vehicle, NSW 2001-2009; a) all injuries and b) serious injuries (SRR ≤ 0.965)

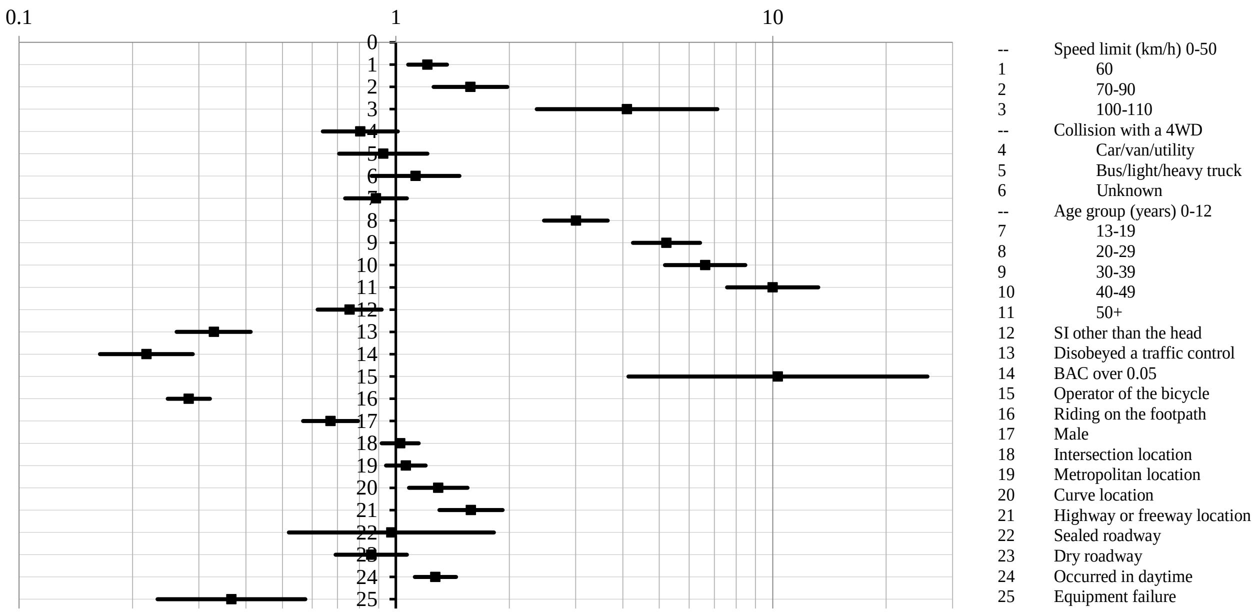

Figure 2: Forest plot of unadjusted associations with helmet use; odds ratios and 95% confidence intervals from univariate logistic regression analysis of cyclist casualties resulting from motor vehicle collisions, NSW 2001-2009 (n=6,745)

TABLES

Data collection	AIS injury Severity[a]	AIS mean SRR[a]	Corresponding SRR range	Injury severity
Police-reported casualty				Possible minor injury
Police-reported casualty + linked APDC record			$0.965 < SRR \leq 1.0$	Moderate injury
Police-reported casualty + linked APDC record	3 – Serious	0.965	$0.854 < SRR \leq 0.965$	Serious injury
Police-reported casualty + linked APDC record	4 – Severe	0.854	$SRR \leq 0.854$	Severe injury

[a] AAAM (2005)

Table 1: Definitions of injury severity

	No helmet		Helmet		Total	
	n	%	n	%	n	%
Speed limit (km/h) 0-50	944	56.9	2542	50.0	3486	51.7
60	595	35.9	1944	38.2	2539	37.6
70-90	105	6.3	446	8.8	551	8.2
100-110	14	0.8	155	3.0	169	2.5
Collision with a 4WD	103	6.2	363	7.1	466	6.9
Car/van/utility	1154	69.6	3274	64.4	4428	65.6
Bus/light truck/heavy truck	202	12.2	659	13.0	861	12.8
Unknown	199	12.0	791	15.5	990	14.7
Age group (years) 0-12	323	19.5	361	7.1	684	10.1
13-19	588	35.5	582	11.4	1170	17.3
20-29	324	19.5	1088	21.4	1412	20.9
30-39	231	13.9	1349	26.5	1580	23.4
40-49	116	7.0	858	16.9	974	14.4
50+	76	4.6	849	16.7	925	13.7
Seriously injured other than the head	157	9.5	372	7.3	529	7.8
Not seriously injured other than the head	1501	90.5	4715	92.7	6216	92.2
Disobeying a traffic control	156	9.4	168	3.3	324	4.8
Not disobeying a traffic control	1502	90.6	4919	96.7	6421	95.2
BAC over 0.05	120	7.2	85	1.7	205	3.0
Not with a BAC over 0.05	1538	92.8	5002	98.3	6540	97.0
Operator of the bicycle	1638	98.8	5081	99.9	6719	99.6
Pillion	20	1.2	6	0.1	26	0.4
Riding on the footpath	570	34.4	655	12.9	1225	18.2
Riding on the roadway	1088	65.6	4432	87.1	5520	81.8
Male	1466	88.4	4256	83.7	5722	84.8
Female	192	11.6	831	16.3	1023	15.2
Intersection location	994	60.0	3082	60.6	4076	60.4
Not at an intersection location	664	40.0	2005	39.4	2669	39.6
Metropolitan location	1159	69.9	3621	71.2	4780	70.9
Rural location	499	30.1	1466	28.8	1965	29.1
Curve location	169	10.2	652	12.8	821	12.2
Not at a curve location	1489	89.8	4435	87.2	5924	87.8
Highway or freeway location	138	8.3	639	12.6	777	11.5
Not at a highway or freeway location	1520	91.7	4448	87.4	5968	88.5
Sealed roadway	1645	99.2	5046	99.2	6691	99.2
Not on a sealed roadway	13	0.8	41	0.8	54	0.8
Dry roadway	1546	93.2	4692	92.2	6238	92.5
Not on a dry roadway	112	6.8	395	7.8	507	7.5
Occurred in daytime	1196	72.1	3903	76.7	5099	75.6
Not in the daytime	462	27.9	1184	23.3	1646	24.4
Equipment failure on bicycle	36	2.2	41	0.8	77	1.1
Not an equipment failure on the bicycle	1622	97.8	5046	99.2	6668	98.9

Table 2: Descriptive characteristics of cyclist casualties resulting from motor vehicle collisions by helmet use, NSW 2001-2009 (n=6,745)

	Cases								Controls			
	Head injury[a]		Skull fracture		Intracranial injury		Open wound		No head injury casualties Control 1		No head injury hospitalisations Control 2	
	n	%	n	%	n	%	n	%	n	%	n	%
Helmet	372	58.2	52	44.1	160	58.4	41	44.6	4715	77.2	924	75.7
No helmet	267	41.8	66	55.9	114	41.6	51	55.4	1391	22.8	296	24.3
Speed limit (km/h) 0-50	302	47.3	60	50.8	125	45.6	40	43.5	3184	52.1	574	47.0
60	223	34.9	37	31.4	90	32.8	33	35.9	2316	37.9	465	38.1
70-90	76	11.9	14	11.9	39	14.2	15	16.3	475	7.8	128	10.5
100-110	38	5.9	7	5.9	20	7.3	4	4.3	131	2.1	53	4.3
Collision with a 4WD	50	7.8	7	5.9	18	6.6	4	4.3	416	6.8	101	8.3
Car/van/utility	392	61.3	66	55.9	168	61.3	60	65.2	4036	66.1	774	63.4
Bus/light/heavy truck	114	17.8	28	23.7	55	20.1	19	20.7	747	12.2	187	15.3
Unknown	83	13.0	17	14.4	33	12.0	9	9.8	907	14.9	158	13.0
Age group (years) 0-12	94	14.7	24	20.3	40	14.6	8	8.7	590	9.7	101	8.3
13-19	127	19.9	30	25.4	66	24.1	18	19.6	1043	17.1	191	15.7
20-29	119	18.6	15	12.7	44	16.1	22	23.9	1293	21.2	220	18.0
30-39	112	17.5	18	15.3	40	14.6	17	18.5	1468	24.0	284	23.3
40-49	81	12.7	13	11.0	33	12.0	11	12.0	893	14.6	200	16.4
50+	106	16.6	18	15.3	51	18.6	16	17.4	819	13.4	224	18.4
SI other than the head	210	32.9	62	52.5	104	38.0	34	37.0	319	5.2	319	26.1
Not	429	67.1	56	47.5	170	62.0	58	63.0	5787	94.8	901	73.9
Disobeyed a traffic control	60	9.4	14	11.9	32	11.7	10	10.9	264	4.3	66	5.4
Not	579	90.6	104	88.1	242	88.3	82	89.1	5842	95.7	1154	94.6
BAC over 0.05	56	8.8	10	8.5	15	5.5	8	8.7	149	2.4	55	4.5
Not	583	91.2	108	91.5	259	94.5	84	91.3	5957	97.6	1165	95.5
Operator of the bicycle	637	99.7	117	99.2	272	99.3	91	98.9	6082	99.6	1214	99.5
Pillion	2	0.3	1	0.8	2	0.7	1	1.1	24	0.4	6	0.5
Riding on the footpath	89	13.9	22	18.6	42	15.3	17	18.5	1136	18.6	193	15.8
Riding on the roadway	550	86.1	96	81.4	232	84.7	75	81.5	4970	81.4	1027	84.2
Male	559	87.5	103	87.3	240	87.6	86	93.5	5163	84.6	1027	84.2
Female	80	12.5	15	12.7	34	12.4	6	6.5	943	15.4	193	15.8
Intersection location	349	54.6	60	50.8	145	52.9	48	52.2	3727	61.0	706	57.9
Not	290	45.4	58	49.2	129	47.1	44	47.8	2379	39.0	514	42.1
Metropolitan location	438	68.5	73	61.9	177	64.6	67	72.8	4342	71.1	881	72.2
Rural location	201	31.5	45	38.1	97	35.4	25	27.2	1764	28.9	339	27.8
Curve location	91	14.2	21	17.8	39	14.2	11	12.0	730	12.0	155	12.7
Not	548	85.8	97	82.2	235	85.8	81	88.0	5376	88.0	1065	87.3
Highway or freeway location	79	12.4	11	9.3	37	13.5	15	16.3	698	11.4	170	13.9
Not	560	87.6	107	90.7	237	86.5	77	83.7	5408	88.6	1050	86.1
Sealed roadway	630	98.6	114	96.6	269	98.2	90	97.8	6061	99.3	1204	98.7
Not	9	1.4	4	3.4	5	1.8	2	2.2	45	0.7	16	1.3
Dry roadway	584	91.4	113	95.8	257	93.8	81	88.0	5654	92.6	1128	92.5
Not	55	8.6	5	4.2	17	6.2	11	12.0	452	7.4	92	7.5
Occurred in daytime	445	69.6	86	72.9	201	73.4	61	66.3	4654	76.2	894	73.3
Not	194	30.4	32	27.1	73	26.6	31	33.7	1452	23.8	326	26.7
Equipment failure	6	0.9	1	0.8	1	0.4	0	0.0	71	1.2	21	1.7
Not	633	99.1	117	99.2	273	99.6	92	100.0	6035	98.8	1199	98.3
Severity $0.965 < SRR \leq 1.0$	367	57.4	16	13.6	132	48.2	82	89.1	--	--	--	--
$0.854 < SRR \leq 0.965$	195	30.5	89	75.4	71	25.9	0	0.0	--	--	--	--
$SRR \leq 0.854$	77	12.1	13	11.0	71	25.9	10	10.9	--	--	--	--

SRR = survival risk ratio – moderate ($0.965 < SRR \leq 1.0$), serious ($0.854 < SRR \leq 0.965$) and severe ($SRR \leq 0.854$)

[a] Head injury includes skull fracture, intracranial injury, open wounds and multiple or other head injuries

Table 3: Descriptive characteristics for cases and controls of cyclist casualties resulting from motor vehicle collisions, NSW 2001-2009

		No head injury casualty controls Control 1				No head injury hospitalisation controls Control 2			
	Injury severity	Odds [a]	CI_L	CI_U	*p*	Odds [a]	CI_L	CI_U	*p*
Head injury	Possible minor injury	1				1			
	Moderate	0.506	0.388	0.659	<.0001	0.577	0.431	0.773	<.0001
	Serious	0.378	0.267	0.536	<.0001	0.435	0.300	0.629	<.0001
	Severe	0.257	0.148	0.448	<.0001	0.285	0.163	0.500	<.0001
Skull fracture	Possible minor injury	1				1			
	Moderate	0.437	0.130	1.466	0.171	0.466	0.137	1.584	0.212
	Serious/severe	0.217	0.132	0.357	<.0001	0.246	0.149	0.408	<.0001
Intracranial injury	Possible minor injury	1				1			
	Moderate	0.626	0.408	0.961	0.029	0.718	0.461	1.117	0.134
	Serious	0.356	0.200	0.633	<.0001	0.374	0.207	0.677	0.001
	Severe	0.284	0.159	0.506	<.0001	0.302	0.169	0.542	<.0001
Open wound	Possible minor injury	1				1			
	Moderate/serious/severe	0.200	0.122	0.330	<.0001	0.224	0.135	0.372	<.0001

[a] odds ratios for wearing a helmet vs not CI_L = lower 95% confidence limit CI_U = upper 95% confidence limit

Table 4: Odds ratios for associations with head injury resulting from helmet use compared with non-helmet use, from multiple variable logistic regression analysis of cyclist casualties resulting from motor vehicle collisions, NSW 2001-2009

		No head injury casualty controls Control 1						No head injury hospitalisation controls Control 2					
	Injury severity	LR[a]	df[b]	AUC[c]	HL[d]	df[b]	*p*	LR[a]	df[b]	AUC[c]	HL[d]	df[b]	*p*
Head injury	Moderate	286	16	0.723	7.80	8	0.453	55	16	0.619	13.02	8	0.111
	Serious	304	16	0.817	7.13	8	0.522	104	16	0.717	1.53	8	0.992
	Severe	176	16	0.849	5.00	8	0.756	80	16	0.776	5.09	8	0.747
Skull fracture	Moderate	70	15	0.884	5.81	8	0.669	32	15	0.843	9.57	8	0.296
	Serious/severe	240	15	0.886	6.80	8	0.558	93	15	0.780	7.53	8	0.480
Intracranial injury	Moderate	104	13	0.732	4.64	8	0.796	29	13	0.641	6.02	8	0.645
	Serious	162	13	0.859	5.08	8	0.749	58	13	0.757	6.47	8	0.485
	Severe	158	13	0.830	5.45	8	0.708	64	13	0.748	9.34	8	0.313
Open wound	Moderate/serious/severe	210	12	0.803	6.21	8	0.515	53	12	0.724	8.72	8	0.273

[a]LR = likelihood ratio, [b]df = degrees of freedom, [c]AUC = area under the receiver operating characteristics curve, [d]HL = Hosmer and Lemeshow statistic

Table 5: Discrimination and goodness-of-fit for the logistic regression models shown in Table 4

	Moderate vs Possible minor injury				Serious vs Possible minor injury				Severe vs Possible minor injury				Variable
	Odds	CI_L	CI_U	*p*	Odds	CI_L	CI_U	*p*	Odds	CI_L	CI_U	*p*	chi-square
Speed limit (km/h) 0-50	1				1				1				
70-90	1.368	0.946	1.979	0.089	1.572	0.961	2.571	0.066	3.104	1.659	5.805	<.0001	16.89
100-110	1.945	1.138	3.325	0.013	2.370	1.219	4.609	0.010	2.450	0.872	6.885	0.083	12.50
Collision with a car/van/utility	1				1				1				
Bus/light/heavy truck	1.064	0.766	1.477	0.706	1.866	1.279	2.723	0.001	1.803	1.026	3.169	0.037	14.14
4WD	1.522	1.039	2.230	0.028	0.987	0.525	1.855	0.967	0.177	0.023	1.356	0.089	8.07
Age group (years) 50+	1				1				1				
0-12	1.016	0.642	1.608	0.946	3.651	1.995	6.684	<.0001	1.230	0.531	2.847	0.622	18.53
13-19	0.760	0.506	1.142	0.178	1.806	1.009	3.231	0.042	0.631	0.282	1.410	0.252	7.95
20-29	0.921	0.643	1.319	0.647	0.690	0.364	1.308	0.246	0.490	0.212	1.133	0.089	4.09
30-39	0.582	0.398	0.850	0.004	1.139	0.651	1.991	0.642	0.376	0.157	0.901	0.025	13.15
40-49	0.677	0.451	1.018	0.056	1.048	0.569	1.931	0.879	0.535	0.218	1.314	0.164	8.43
Serious injury other than head	6.390	4.872	8.381	<.0001	9.917	7.070	13.911	<.0001	13.263	8.048	21.859	<.0001	375.7
Helmet	0.506	0.388	0.659	<.0001	0.378	0.267	0.536	<.0001	0.257	0.148	0.448	<.0001	70.48
Disobeyed a traffic control	1.738	1.159	2.605	0.006	0.967	0.522	1.789	0.912	3.166	1.632	6.140	0.001	18.14
BAC over 0.05	3.468	2.257	5.329	<.0001	4.086	2.289	7.294	<.0001	0.897	0.202	3.974	0.884	48.89
Riding on the footpath	0.510	0.361	0.721	<.0001	0.343	0.212	0.556	<.0001	1.014	0.569	1.808	0.962	32.77

Moderate ($0.965 < SRR \leq 1.0$), serious ($0.854 < SRR \leq 0.965$), severe ($SRR \leq 0.854$)
CI_L = lower 95% confidence limit CI_U = upper 95% confidence limit

Table 6: Odds ratios for associations with all head injury (compared with no head injury casualty controls), from multiple variable logistic regression analysis of cyclist casualties resulting from motor vehicle collisions, NSW 2001-2009 (model diagnostics are shown in Table 5)

APPENDIX A

ICD-10 code	SRR	ICD-10 code	SRR	ICD-10 code	SRR	ICD-10 code	SRR
S01.0	0.9728	S06.02	0.9957	S06.28	0.7172	S06.6	0.7365
S01.83	0.7805	S06.03	0.7905	S06.30	1.0000	S06.8	0.6523
S02.0	0.8817	S06.04	0.9333	S06.31	0.9445	S06.9	0.7045
S02.1	0.8675	S06.05	0.2840	S06.32	0.9444	S09.7	0.6444
S02.7	0.5875	S06.1	0.6756	S06.33	0.9322	S09.8	0.9449
S02.8	0.9408	S06.20	0.8485	S06.34	1.0000	S09.9	0.8898
S02.9	0.4442	S06.21	0.8675	S06.38	1.0000		
S06.00	0.9952	S06.22	0.8889	S06.4	0.9236		
S06.01	0.9243	S06.23	0.8668	S06.5	0.8233		

Table A1: Survival risk ratios (SRR) for ICD-10 head injury codes

APPENDIX B

In order to assess the linkage rates (police-reporting rates) and associated attributes, the APDC data were restricted to admissions resulting from crashes involving pedal cyclists that collided with a motor vehicle (first external cause codes ICD-10-AM: V12, V13 or V14). The police-reported crash data were then linked to these cases using the PPN and index admission date (same day or next). The overall linkage rate was 70.7%. The results are presented in Table B1, and are disaggregated according to the variables available in the APDC. Variables that statistically significantly affected linkage rates were if the individual was covered by the compensable motor vehicle insurance act (MVA), and those related to the severity of the injury (died, seriously injured, admitted to intensive care, length of stay greater than 5 days). Individuals whose crash injuries were covered by insurance, or whose injuries were more serious, were more likely to be police-reported and appear in the population of cyclist casualties used in the present study. Since the variations from the average of 70.7% are generally small, it may be concluded that, within the limitation of the variables available in the APDC, the data used in the present study is generally applicable to the wider population of cyclists involved in collisions with motor vehicles in NSW (2001 – 2009).

Variable	% linked	Variable	% linked
Age (*p*=0.062)		**Separation mode (*p*=0.022)** [b]	
< 15	69.1	Died	85.3
15 – 19	74.2	Discharged	69.9
20 – 24	67.7	Transferred	75.1
25 – 34	70.1	**Injury severity (*p*=0.006)** [b]	
35 – 44	72.7	Not serious	69.0
45 – 54	68.6	Serious [a]	73.9
55 – 64	78.1	**Intensive care (*p*=0.015)** [b]	
≥ 65	63.9	Yes	80.5
Payment status (*p*<0.001) [b]		No	70.3
Compensable (MVA)	79.8	**Length of stay (*p*=0.018)** [b]	
Other	65.2	< 5 days	69.6
Gender (*p*=0.942)		≥ 5 days	74.4
Male	70.9		
Female	70.7		

[a] serious injured defined by SRR≤0.965
[b] statistically significantly associated with linkage (univariate analysis, $p<0.05$)

Table B1: Analysis of linkage rates for cyclist casualties resulting from motor vehicle collisions, NSW 2001-2009