# The effects of bicycle helmet legislation on cycling-related injury: the ratio of head to arm injuries over time

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## Abstract
Legislation for the mandatory use of bicycle helmets is a controversial issue. The analysis presented in this paper examines the ratio of cycling-related head to arm injuries using hospital admissions data in New South Wales. The analysis is based on the idea that even if the numbers of cyclists has dropped over time, the relative injury rates (head versus arm) should remain unchanged unless some factor is differentially impacting on one type of injury, for example, helmet use reducing head injuries but not affecting arm injuries.

Results indicate that there was already a fall in the ratio of head to arm injuries before the mandatory helmet legislation was introduced in 1991. After the introduction of bicycle helmet legislation, there was a continued but declining reduction in the ratio of head injuries relative to arm injuries for most age groups. It is likely that factors other than the mandatory helmet legislation reduced head injuries among cyclists.

## Introduction

While the health benefits of cycling are generally agreed upon [1] the risks associated with cycling are a more contentious issue. One early analysis calculated that the benefits of cycling outweighed the risks by a ratio of 20:1 [2]. Methods of calculation of risk vary considerably, from the number of people hurt or killed while cycling, to the rates of morbidity or mortality per million kilometres cycled [3,4].

In New South Wales (NSW) in the fiscal year 2005/6 there were 2,737 serious land transport injuries among people cycling, and there were 16,147 serious injuries to all road users in the same period [5] Seven people in NSW were killed while cycling in 2006.[6] Across Australia, 93.3% of all traffic related cycling injuries occurred in children aged 5-17 years.[5] However, it is difficult to accurately assess the risks associated with cycling without a clear denominator. For example, the number of cycling related hospitalisations within a given time period needs to be considered in the context of how many people cycled during that period or how far they cycled or for how long.

Head injuries are the most common cause of bicyclist fatalities and serious disability,[7] which, in Australia has led to mandatory helmet legislation. Legislation for the mandatory use of bicycle helmets is a controversial issue internationally,[8-10] with different research methodologies such as case-control studies and population based studies, reaching different conclusions.[11] Australia and New Zealand are the only two countries in the world with mandatory adult helmet use laws, introduced in Australia for adults on January 1 1991, and for children under 16 years from July 1991.

Advocates for helmet use cite evidence from bio-mechanical tests and case-control studies that repeatedly show that helmets protect against impact to the head,[12,13] if worn correctly.[14] Anti-helmet advocates claim that mandatory helmet legislation has reduced the number of people cycling and this has led to reductions in cycling-related injuries attributed to the legislation. The reduction in numbers of people cycling may have actually increased the risk to the remaining cyclists because of Smeed's Law and the safety in numbers hypothesis.[15] Further, they argue that the debate over what impact protection helmets may provide is a distraction from the main bicycle related health issue: the safety of the bicycling environment [16] and that cost-benefit analyses do not support mandatory helmet use [16,17].

This paper seeks to investigate the impact of the mandatory helmet legislation on head injuries in New South Wales (NSW), Australia, by examining the ratio of cycling-related head to arm injuries. The analysis is based on the idea that even if the numbers of cyclists has dropped over time, the relative injury rates (head versus arm) should remain unchanged unless some factor is differentially impacting on one type of injury, for example, helmet use reducing head injuries but not affecting arm injuries. Arm injuries, rather than leg injuries were chosen, as arm injuries are more closely located in relation to the upper torso and head.

## Method

Data on hospital separations in New South Wales were obtained from the NSW Inpatients Statistics Collection (now known as Admitted Patients Data Collection) from 1988/89 (the earliest year data were available) to 2007/08.[18] In 1998/99 the system used to code this data changed from ICD9 to ICD10, with two years of injuries being coded using both sets of definitions. For this paper we have used ICD10 coding, and mapped ICD10 codes onto ICD9 codes for data before 1998/1999.

External causes of hospitalisations referring to pedal cyclists were selected as cases using ICD10 codes V01.00-V19.99.[19] These data include all cyclist injuries, not only those involving road traffic [20].

The data were categorised according to principal diagnosis using ICD10 codes. Only codes representing injuries to arm or hand and head injuries were used in the study (see Table 1). Cases that had both head and arm injuries were counted in each group. For data from records that used ICD9 codes cases were selected by mapping codes from ICD10 to ICD9.[20] The years for which both ICD9 and ICD10 were used (1998-2000) indicate that the ratio of head to arm injuries was higher using the ICD10 codes. All data were tabulated using Microsoft Excel 1997. The ratio of head to arm/hand injuries was calculated by dividing the number of head injuries by the number of arm/hand injuries for each data collection year (1988/89-2007/08). These calculations were also stratified by age groups (0-14 years, 15-24 years, 25-49 years, 50 years and older). Helmet use compliance was based on data from a report by Smith and Milthorpe [21], which is the best available data.

**Table 1**: ICD10 codes corresponding to Arm/hand and head injuries

| **Place of injury** | **ICD10 code** |
|---|---|
| Head injuries | S00-S09 |
| Arm/hand injuries | S40-S49 Injuries to the shoulder and upper arm<br>S50-S59 Injuries to the elbow and forearm<br>S60-S69 Injuries to the wrist and hand |

## Results

From 1988/89 - 2007/08 there were 22,017 cases of cyclists being hospitalized due to injuries sustained to their hand or arm and 18,370 cases due to injuries sustained to the head. Cases aged less than 14 years of age were over-represented in the data with approximately 51% of severe arm/hand injuries and 47% of severe head injuries occurring in this age group (Figure 1).

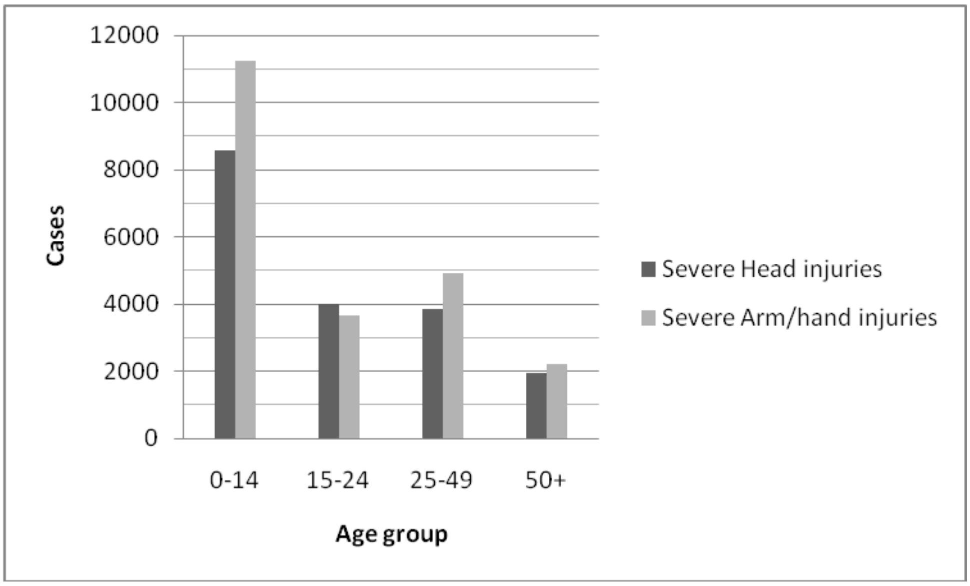


**Figure 1:** Number of hospital separations for cyclists by age group and selected location of principle injury, NSW 1997/98-2007/08

The total number of head injuries declined from 702 in 1988/89 to 581 in 1999/2000, with the most marked decline in the 0-14 years age group (Table2). However, the majority of the decline occurred prior to the helmet legislation, and before helmet use compliance increased. Figure 2 shows the ratio of head to arm injuries declining steeping from 1988/1989 to 1990/1991 (mandatory helmet legislation was enacted for adults on January 1, 1991) and then continued to decline slightly before leveling out. This pattern for the ratio of head to arm injuries is evident for all age groups (Table 3).

For children aged 5- 14 years, the greatest decline in the ratio of head to arm injuries was in the two fiscal years 1990/91-1991/92, demonstrating the strongest temporal association with the introduction of the legislation, although there had been similar decreases before the legislation and the decline flattens out after 1994. For 15-24 year olds, there was a strong decline in the ratio of head to arm injuries from 1991/92 to 1992/93 fiscal year before increasing again and then leveling out. For both the 25-49 and over 50 years age groups, the greatest declines were before the 1991/92 fiscal year, with ratios leveling out soon after.

There was a lag between the introduction of the helmet legislation and compliance with the law, such that actual wearing of helmets by a majority of the population took six to twelve months. Compliance for all ages increased from approximately 18% to 78% three years after the legislation (see Figure 2).[21] Because of the delayed (by six months) introduction for children, helmet wearing by children under 16 years is correspondingly later.

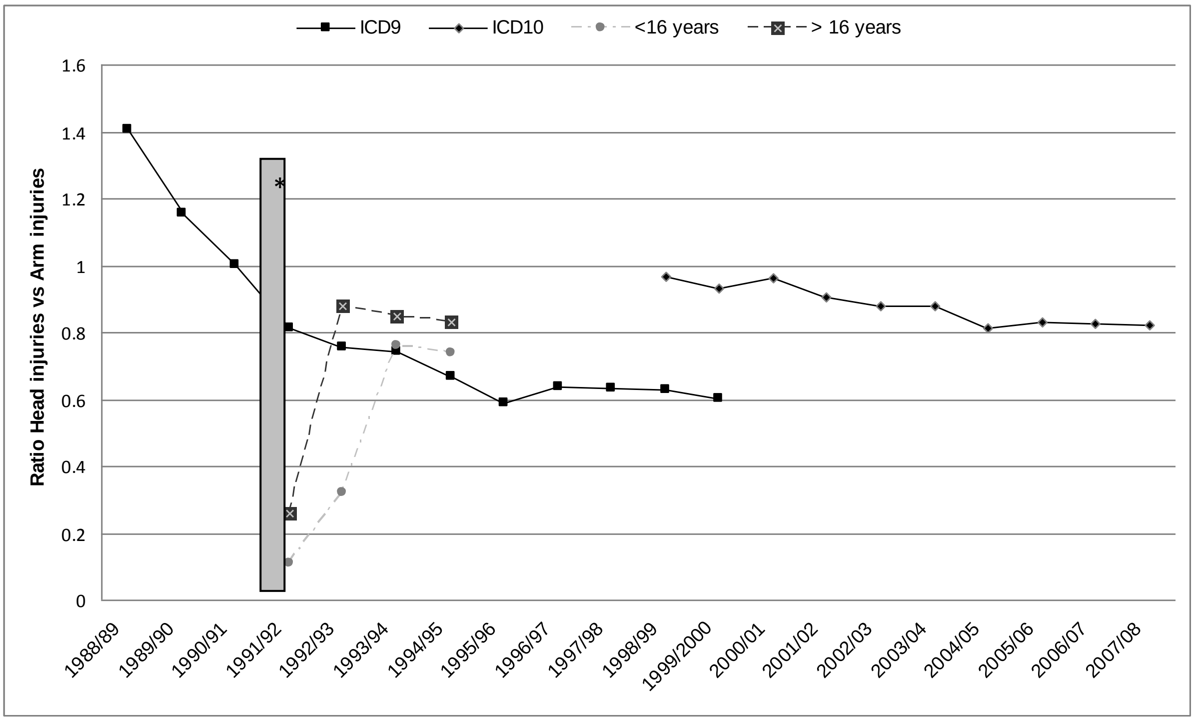


Figure 2: Ratio of head to arm injuries from 1988/9 to 2007/8 for all ages, plus self-reported helmet use for those younger than 16 years, and over.
** Mandatory helmet wearing legislation introduced for adults January 1, 1991*

[Insert Table 2 and 3 about here]

## Discussion

It is apparent from the results that the ratio of head to arm injuries was already declining in NSW before the introduction of mandatory helmet legislation, and certainly before the self-reported level of helmet use increased. This is consistent with other data indicating a general decline in motor vehicle related fatalities and morbidity in NSW from 1950 to the present, but in particular between 1980 and 1990.[6] A similar pattern of decline is evident for pedal cycle fatalities, with a steep drop in cycling deaths from 1989 (98) to 1992 (41), corresponding with a similar drop in head injuries.[22]

It is most likely that a series of changes in road safety and conditions before 1991 contributed to a generally safer road environment, which benefited people cycling as well as other road users. For example, on December 17, 1982, New South Wales, introduced random breath testing, with an immediate decline in road deaths, which soon stabilized at a rate approximately 22 percent lower than the average for the previous 6 years.[23] The introduction of intensive road safety advertising in 1989, and the introduction of speed camera programs in 1990, plus the implementation of national road safety strategies (e.g., STAYSAFE Committee) all contributed to marked reductions in traffic related mortality and morbidity through the 1980s and early 1990s.[24]

The analysis presented here explored the relationship between mandatory helmet legislation and head injuries among cyclists by removing problems due to a lack of the number of people cycling as a denominator. Using hand/arm injuries by cyclists as a control means that cyclists are compared with cyclists, and that any change in the ratio of the head to arm injuries should be the result of a change in practice, such as helmet wearing. Two other previous papers looking at the impact of helmet legislation reported on pedestrian deaths and head injuries as a comparison with cyclists before and after 1991. Robinson found a decline in deaths and serious head injuries among pedestrians paralleled the decline in these injuries among cyclists between 1988 and 1992.[15] Between 1988 and 1994 the decline in deaths from head injuries among pedestrians was 8% greater than the decline in deaths from head injuries among cyclists.[25] Clearly pedestrians are not affected by helmet legislation, yet the reduction in head injuries among pedestrians supports the idea that factors other than helmets may be responsible for generally safer road conditions.

New Zealand introduced mandatory helmet legislation on January 1, 1994. There was a dramatic increase in helmet use and a 51% drop in the number of trips by bicycle between 1989/90 and 2003-6 [26]. An analysis of changes in head injury rates noted a gradual decline over time, but no marked improvement associated with increased helmet use compliance [27]. Robinson criticized the results, noting that, similar to the NSW data, the ratio of head injuries to limb injuries among cyclists had begun falling well before New Zealand's helmet law went into effect [28]. Between 1993 and 1994, the law dramatically increased helmet use from 43 percent to 93 percent of cyclists, but head injuries continued declining at the same rate as before [28]. An examination of road user fatalities in New Zealand found that cyclist fatalities did not fall at any greater rate than for other road users after law enforcement in 1994, even with fewer people cycling [29].

Four provinces in Canada have helmet legislation for children ages less than 18 years, with one analysis of head injury rates before and after the legislation demonstrating reductions in head injury rates [30]. However, in two of the provinces (Ontario, British Columbia) representing 89% of the total data set, again most of the falls in head injuries took place before the laws came into effect [31]. In British Columbia head injury increased in the year following the law and then declined at a rate not significantly different to no-law provinces. In Ontario post-law the decline in head injuries was also similar to non-law provinces [31]. This suggests that changes in the road environment or other factors, rather than helmet legislation, may have been responsible for the changes.

Sweden is the only other country to introduce mandatory helmet legislation, in their case for children under 15 years of age in 1991. Data from the Swedish National Road and Transport Research Institute show clearly that helmet use increased since 1991, and over the same period the number of children cycling declined [32]. Israel and Mexico City have introduced helmet legislation, but subsequently repealed it [33], in part because of the difficulties it created for introducing free bicycle loan schemes.

With approximately half of the head injuries reported in the present study being among young people, this group warrants further attention for cycling safety. Although general improvements to the road environment and cycling conditions will benefit children, their relatively lower levels of cycling skills and road awareness may mean that mandatory helmet wearing should continue for children, provided it does not lead to reduced numbers of children cycling. The case for continued mandatory helmet wearing for adults is questionable.

**Limitations**

The transition from ICD9 to ICD10 codes has meant some inconsistencies in tracking over time. We mapped ICD10 codes onto ICD9 codes, although the mapping is not perfect. The hospitalisations used in this analysis represent the most severe cases and other important cycling-related injuries such as unreported injuries or Emergency Department presentations (although less severe) are excluded. Also, analysis of population-level hospital separation data which is collected for other purposes, does not allow the attribution of any direct causal effect or non-effect of the introduction of mandatory helmet use legislation on injury rates. Other possible confounders may explain apparent relationships. However, from a practical and policy perspective, the introduction of mandatory helmet legislation does not appear to be temporally associated with a substantial drop in head injuries among cyclists. An analysis with more consistently coded data and with statistical testing would be important to confirm or refute these observations.

## Conclusion

The main conclusion of this examination of the ratio of head to arm injuries over time is that there was a marked decline in head injuries among pedal cyclists before the introduction of mandatory helmet legislation and behavioural compliance, most likely a result of a range of other improvements to road safety. Helmet use is likely to prevent some head injury, particularly for younger age groups, and may also reduce severity of injury. However, the mandatory bicycle helmet legislation appears not to be the main factor for the observed reduction in head injuries among pedal cyclists at a population level over time.

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## Table 2: Cases of head and arm injuries for hospitalised cycling-related injuries by age group

| | 0-14 | | | | 15-24 | | | | 25-49 | | | | 50+ | | | | All ages | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | head | | Arm | | head | | arm | | head | | arm | | head | | arm | | head | | arm | |
| | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 | icd9 | icd10 |
| **1988/89** | 421 | | 334 | | 134 | | 92 | | 87 | | 59 | | 20 | | 14 | | 702 | | 499 | |
| **1989/90** | 423 | | 409 | | 193 | | 128 | | 108 | | 69 | | 23 | | 26 | | 770 | | 666 | |
| **1990/91** | 356 | | 338 | | 152 | | 98 | | 94 | | 73 | | 27 | | 32 | | 640 | | 638 | |
| **1991/92** | 291 | | 397 | | 133 | | 92 | | 85 | | 92 | | 18 | | 28 | | 509 | | 627 | |
| **1992/93** | 310 | | 446 | | 124 | | 128 | | 98 | | 130 | | 16 | | 31 | | 579 | | 765 | |
| **1993/94** | 315 | | 476 | | 126 | | 112 | | 89 | | 103 | | 21 | | 40 | | 513 | | 692 | |
| **1994/95** | 311 | | 521 | | 112 | | 117 | | 88 | | 135 | | 26 | | 31 | | 505 | | 756 | |
| **1995/96** | 330 | | 617 | | 128 | | 162 | | 91 | | 133 | | 13 | | 43 | | 532 | | 904 | |
| **1996/97** | 373 | | 595 | | 143 | | 175 | | 81 | | 139 | | 18 | | 50 | | 581 | | 913 | |
| **1997/98** | 386 | | 640 | | 146 | | 155 | | 96 | | 178 | | 24 | | 41 | | 618 | | 979 | |
| **1998/99** | 288 | 554 | 484 | 587 | 120 | 223 | 146 | 209 | 93 | 224 | 147 | 243 | 20 | 157 | 38 | 173 | 511 | 1170 | 812 | 1212 |
| **1999/2000** | 339 | 620 | 567 | 712 | 137 | 281 | 166 | 234 | 97 | 269 | 185 | 315 | 18 | 147 | 52 | 157 | 581 | 1323 | 966 | 1421 |
| **2000/01** | | 574 | | 612 | | 272 | | 251 | | 274 | | 299 | | 142 | | 157 | | 1293 | | 1341 |
| **2001/02** | | 466 | | 615 | | 256 | | 226 | | 321 | | 379 | | 185 | | 169 | | 1321 | | 1462 |
| **2002/03** | | 544 | | 675 | | 230 | | 241 | | 310 | | 379 | | 181 | | 177 | | 1355 | | 1540 |
| **2003/04** | | 479 | | 678 | | 248 | | 227 | | 317 | | 403 | | 96 | | 171 | | 1519 | | 1731 |
| **2004/05** | | 480 | | 753 | | 256 | | 255 | | 279 | | 387 | | 187 | | 187 | | 1514 | | 1863 |
| **2005/06** | | 496 | | 641 | | 291 | | 271 | | 329 | | 493 | | 198 | | 233 | | 1624 | | 1956 |
| **2006/07** | | 445 | | 657 | | 294 | | 266 | | 331 | | 475 | | 224 | | 232 | | 1619 | | 1955 |
| **2007/08** | | 403 | | 526 | | 248 | | 219 | | 301 | | 438 | | 208 | | 216 | | 1443 | | 1754 |

**Table 3: Ratio of head to arm injuries for hospitalised cycling-related injuries by age group**

| | 0-14 | | 15-24 | | 25-49 | | 50+ | | All Ages | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ICD9 | ICD10 | ICD9 | ICD10 | ICD9 | ICD10 | ICD9 | ICD10 | ICD9 | ICD10 |
| **1988/89** | 1.260479 | | 1.456522 | | 1.474576 | | 1.428571 | | 1.406814 | |
| **1989/90** | 1.03423 | | 1.507813 | | 1.565217 | | 0.884615 | | 1.156156 | |
| **1990/91** | 1.053254 | | 1.55102 | | 1.287671 | | 0.84375 | | 1.003135 | |
| **1991/92** | 0.732997 | | 1.445652 | | 0.923913 | | 0.642857 | | 0.811802 | |
| **1992/93** | 0.695067 | | 0.96875 | | 0.753846 | | 0.516129 | | 0.756863 | |
| **1993/94** | 0.661765 | | 1.125 | | 0.864078 | | 0.525 | | 0.741329 | |
| **1994/95** | 0.596929 | | 0.957265 | | 0.651852 | | 0.83871 | | 0.667989 | |
| **1995/96** | 0.534846 | | 0.790123 | | 0.684211 | | 0.302326 | | 0.588496 | |
| **1996/97** | 0.626891 | | 0.817143 | | 0.582734 | | 0.36 | | 0.636364 | |
| **1997/98** | 0.603125 | | 0.941935 | | 0.539326 | | 0.585366 | | 0.631256 | |
| **1998/99** | 0.595041 | 0.943782 | 0.821918 | 1.066986 | 0.632653 | 0.921811 | 0.526316 | 0.907514 | 0.62931 | 0.965347 |
| **1999/2000** | 0.597884 | 0.870787 | 0.825301 | 1.200855 | 0.524324 | 0.853968 | 0.346154 | 0.936306 | 0.601449 | 0.931034 |
| **2000/01** | | 0.937908 | | 1.083665 | | 0.916388 | | 0.904459 | | 0.964206 |
| **2001/02** | | 0.757724 | | 1.132743 | | 0.846966 | | 1.094675 | | 0.903557 |
| **2002/03** | | 0.805926 | | 0.954357 | | 0.817942 | | 1.022599 | | 0.87987 |
| **2003/04** | | 0.70649 | | 1.092511 | | 0.7866 | | 0.561404 | | 0.877527 |
| **2004/05** | | 0.63745 | | 1.003922 | | 0.72093 | | 1 | | 0.812668 |
| **2005/06** | | 0.773791 | | 1.073801 | | 0.667343 | | 0.849785 | | 0.830266 |
| **2006/07** | | 0.677321 | | 1.105263 | | 0.696842 | | 0.965517 | | 0.828133 |
| **2007/08** | | 0.76616 | | 1.13242 | | 0.687215 | | 0.962963 | | 0.822691 |