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HEAD INJURIES AND BICYCLE HELMET LAWS

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Abstract—The first year of the mandatory bicycle helmet laws in Australia saw increased helmet wearing from 31% to 75% of cyclists in Victoria and from 31% of children and 26% of adults in New South Wales (NSW) to 76% and 85%. However, the two major surveys using matched before and after samples in Melbourne (Finch et al. 1993; Report No. 45, Monash Univ. Accident Research Centre) and throughout NSW (Smith and Milthorpe 1993; Roads and Traffic Authority) observed reductions in numbers of child cyclists 15 and 2.2 times greater than the increase in numbers of children wearing helmets. This suggests the greatest effect of the helmet law was not to encourage cyclists to wear helmets, but to discourage cycling. In contrast, despite increases to at least 75% helmet wearing, the proportion of head injuries in cyclists admitted or treated at hospital declined by an average of only 13%. The percentage of cyclists with head injuries after collisions with motor vehicles in Victoria declined by more, but the proportion of head injured pedestrians also declined; the two followed a very similar trend. These trends may have been caused by major road safety initiatives introduced at the same time as the helmet law and directed at both speeding and drink-driving. The initiatives seem to have been remarkably effective in reducing road trauma for all road users, perhaps affecting the proportions of victims suffering head injuries as well as total injuries. The benefits of cycling, even without a helmet, have been estimated to outweigh the hazards by a factor of 20 to 1 (Hillman 1993; Cycle helmets—the case for and against. Policy Studies Institute, London). Consequently, a helmet law, whose most notable effect was to reduce cycling, may have generated a net loss of health benefits to the nation. Despite the risk of dying from head injury per hour being similar for unhelmeted cyclists and motor vehicle occupants, cyclists alone have been required to wear head protection. Helmets for motor vehicle occupants are now being marketed and a mandatory helmet law for these road users has the potential to save 17 times as many people from death by head injury as a helmet law for cyclists without the adverse effects of discouraging a healthy and pollution free mode of transport. Copyright © 1996 Elsevier Science Ltd

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INTRODUCTION

A number of studies comparing head injury rates of helmeted and non helmeted cyclists receiving emergency treatment have concluded that wearing a bicycle helmet significantly reduces the risk of head injury. A recent review by a US Government Agency (CDC 1995), for example, cites as evidence investigations in Seattle (Thompson et al. 1989), South Australia (Dorsh et al. 1987), Vermont (Wasserman et al. 1988) and a questionnaire administered to 191 readers of 4 US bicycle magazines (Wasserman and Buccini 1990). The first study estimated a reduction of 74%–85% in head injuries from helmet wearing. In the other three studies, crude odds ratios for increased risk of head injury in unhelmeted cyclists were 4.2, 19.6 and 4.5. To establish national benefits, the review cited a further study (Sacks et al. 1991) which, estimating wearing rates at less than 2% of youngsters and 10% of all US cyclists, predicted a total of 500 deaths and 151,400 out of 181,150 US non fatal bicycle related head injuries might be prevented annually if all cyclists wore helmets.

Estimates of risk from comparisons of helmeted and non helmeted cyclists, however, are based on the assumption that cyclists who choose to wear helmets are comparable in all other respects to bareheaded riders. In Seattle, an observational study showed children wearing helmets were much more often white than black or other races and riding in parks or bicycle paths than on city streets (DiGuisseppi et al. 1989). There is a danger such studies may control inadequately for rider behaviour or other factors and so attribute these differences to the effect of helmets.

Helmet wearing may also alter a cyclist's attitudes towards risk (Hillman 1993). Cyclists feel protected by helmets (Elliott and Shanahan 1986), so may take more risks and have more accidents. The 85% reduction in head injuries from helmet wearing in Seattle was derived mainly from a comparison of a 21.1% helmet wearing rate in a control group of children from families in a healthcare cooperative who had cycling accidents and a wearing rate of 2.1% in head injured child cyclists. However, in Seattle in May and September 1987, the same time as the investigation into helmet effectiveness at the five major teaching hospitals, the observational study (DiGuisseppi et al. 1989) found helmet wearing rates of only 3.1% and 3.3% in samples of 1957 and 2544 child cyclists. If cyclists riding around Seattle had been considered the control population, rather than those who had accidents, a rather different conclusion might have been reached about the effectiveness of helmets.

Indeed, helmet use in South Australia at the time of the Dorsch study (1980–1985) would have been relatively low, but 62% of the cyclists who reported hitting their heads were wearing a helmet at the time. An almost identical proportion, 57% of the 191 readers of US bicycle magazines responding to a request for details concerning hitting their heads in a bicycle accident from 1980–1985 reported wearing a helmet at the time. In contrast to these unusually high wearing rates, the Vermont study interviewed cyclists at roadside stations and observed only 40/516 (7.8%) wearing helmets. Yet when it came to reporting hitting their heads in the past 18 months, this had happened to 8 cyclists wearing a helmet compared to only 13 without. Assuming the observed helmet wearing was typical of the cyclists' regular habits, head injury rates in helmeted and non helmeted cyclists (7/476 vs 0/40) were therefore not significantly different ($p>0.55$), but the incidence of hitting their heads in a cycling accident was most significantly higher for helmet wearers (8/40 vs 13/476 i.e. 20% vs 2.7%; $p<0.00001$).

Based on predictions of substantially reduced head injury rates, Australia was the first country in the world to introduce mandatory helmet laws for cyclists. As a result, wearing rates in Victoria increased from 31% to 75%. In New South Wales (NSW), wearing increased from 26% to 85% in adults and 31% to 76% in children. This article compares the observed changes in head injury with pre law predictions to see how they measured up to reality. Changes in head and other injuries are also compared to changes in the amount of cycling, to test the possibility of risk compensation and see if the substantially increased helmet wearing resulted in a higher accident rate for cyclists.

RESULTS

Effect of the law on numbers of cyclists and head injuries in NSW

In NSW, the effect of the helmet law was determined (Smith and Milthorpe 1993) by counting cyclists under 16 at school (19 Sydney and 12 regional secondary schools, 16 Sydney and 12 regional primary schools), road intersections (25 Sydney, 14 regional) and recreational areas (12 Sydney, 10 regional). Counts were taken at the same time of year (April), in similar weather conditions, at the same sites and times and, where possible, using the same observers to make the two post law surveys as comparable as possible with the pre law survey. Comparable figures were not available for adults. The helmet law was introduced for child cyclists on 1 July, 1991.

It is immediately apparent from Table 1 the greatest effect of the law was not to increase numbers of child cyclists wearing helmets, but to decrease total numbers of child cyclists. For example, by 1993, 569 more children were observed wearing helmets, but the total decrease in numbers counted, 2658, was nearly five times larger. Indeed, by 1993, 44% fewer child cyclists were counted than before the law. The reduction in the first year was 36% with almost identical reductions in rural NSW (35%) and the Sydney metropolitan area (37%).

With 36% and 44% fewer child cyclists in the first and second years of the law, it would have been expected that, even if helmets had no effect, head and other injuries to child cyclists would reduce commensurately. Table 2, showing admissions to all public hospitals after cycling injuries, indicates this has not been the case. Neither the number of head injuries, nor the number of injuries to other parts of the body have declined as much as the estimated amount of cycling. This suggests the risk of injury, both to the head and elsewhere, is higher than before the law, and for 1993 there would have been 488 head injuries to child cyclists instead of the pre law number of 384, had similar numbers been on the roads as before the law.

A proportion of cycling injuries relate to motor vehicles and thus may be affected by the overall road safety climate. Reduced vehicle speeds from traffic calming, the introduction of speed cameras and increased random breath testing have all been shown to reduce casualties. Conversely, increased traffic following recovery from recession or less vigilant enforcement of traffic laws may decrease overall road safety and so increase injuries to cyclists. To investigate whether the apparent increased risk of head and other injuries indicated by Table 2 could have been due to changed road safety conditions, injuries of cyclists in road accidents reported to police in NSW were compared with those for pedestrians and other road users.

In fact, reported deaths and serious injuries (DSI) to all child road users, including pedestrians, declined quite dramatically over the period (Table 3). While

Table 1. Counts of child cyclists in NSW before and in the first two years of the bicycle helmet law (from Walker 1992; Smith and Milthorpe 1993)

Year	1991 (pre law)		1992 (1st law year)		1993 (2nd law year)	
Location	Total counted	No.* helmeted	Total counted	No.* helmeted	Total counted	No.* helmeted
Road Intersections	1741	440	1188	874	881	582
Change from 1991			−553	434	−860	142
Recreational areas	1742	709	1236	899	1184	872
Change from 1991			−506	190	−558	163
School gates	2589	761	1433	1156	1349	1025
Change from 1991			−1156	395	−1240	264
Total child cyclists	6072	1910	3857	2929	3414	2479
Change from 1991			−2215	1019	−2658	569

*Numbers helmeted obtained by multiplying sample size by percentage wearing helmets.

Table 2. Injuries of cyclists under 16 admitted to hospital in NSW (Source NSW Health Department) compared with estimated amount of cycling

Year to end June	No of head injuries (H)	No of non head injuries (O)	No of cyclists (Proportion of 1991) (N)	Equivalent no of injuries for pre law numbers of cyclists: Head injury ($= H/N$)	Other injury ($=O/N$)
1989	414	908			
1990	453	1053			
1991	384	926	1.00	384	926
1992	272	815	0.64	425	1273
1993	273	893	0.56	488	1595

Table 3. Numbers of reported deaths and serious injuries (DSI) for various road users aged 0–16 in NSW (from Road Traffic Accidents in NSW)

Year to end December	Reported DSI, all child road users	Reported Pedestrian DSI, (P)	Reported DSI, Cyclists (C)	No of cyclists (proportion of pre law), (N)	DSI for pre law no of cyclists ($R=C/N$)	Cyclist DSI vs Pedestrian $= R/P$
1989	1207	380	175			
1990	1037	354	152	1.00	152	0.43
1991	877	315	115			
1992	836	316	97	0.64	152	0.48
1993	829	281	103	0.56	184	0.65

this appeared also to be the case for child cyclists, if similar numbers of child cyclists had been on the roads in 1993 as before the law, DSI to child cyclists would have increased by 21%, compared with a decrease of 21% for child pedestrians and 20% for child road users in general. This would appear to represent a moderate increase relative to other child road users in the risk of death or serious injury for child cyclists in the years after the helmet law.

Effect of the law in Victoria

In Victoria, the helmet law was introduced for both adult and child cyclists on 1 July 1990. Comprehensive counts of numbers of cyclists pre and post law were conducted by Monash University Accident Research Centre at 64 sites in Melbourne in May 1990 (pre law) and in May 1991 and 1992 (Finch et al. 1993). The sites were chosen as a representative sample of the roads in Melbourne. In all three years, the same sites and observation times were used.

Table 4 shows, in the first year of the Victorian helmet law, the reduction in numbers counted was 4 times greater than the increase in cyclists wearing helmets. In the second year, a bicycle rally happened to pass through one of the 64 sites. Numbers of cyclists at that particular site increased from 72 in 1991 to 451 in 1992, 81% of the total increase. Despite the 1992 rally, compared with before the law, numbers counted decreased by almost as much as the increase in helmet wearing and the decrease in numbers of child cyclists was nearly three times the increase in numbers of helmeted child cyclists. Thus both in NSW and Victoria, even two years after the law, the estimated decrease in numbers of child cyclists was 3–5 times greater than the increase in numbers wearing helmets.

Table 4. Counts of cyclists in Victoria before and during the first two years of the bicycle helmet law (from Finch et al. 1993)

Year	1990 (Pre law)		1991 (1st law year)		1992 (2nd law year)	
Age group	Total counted	No. helmeted	Total counted	No. helmeted	Total counted	No. helmeted
Children up to 11 years	261	170	235	183	281	216
Change from 1990			−26	13	20	46
Children 12–17 years	1293	272	670	302	713	421
Change from 1990			−623	30	−580	149
Adult cyclists	1567	564	1106	818	1484	1247
Change from 1990			−461	254	−83	683
All cyclists	3121	1006	2011	1303	2478	1884
Change from 1990			−1110	297	−643	878

As well as counting cyclists, the time taken to travel through marked areas was recorded for children in 1990 and all cyclists in 1991 and 1992. These recorded times were used to estimate total cycle use which, in children to age 17 was estimated to have decreased by 33% and 36% in the first and second years of the law (Finch et al. 1993). Estimates of cycle use in Melbourne may then be compared with numbers of head and other injuries in child cyclists (under 15 years) treated at three Melbourne hospitals (Western, Preston and Northcote, and Royal Children's) participating in the Victorian Injury Surveillance System (VISS 1993). Some caution must be exercised because of the discrepancy in age ranges, but Table 5 suggests, as in NSW, for the same child cycle use as before the law there would now be no fewer head injuries and more total injuries.

To investigate the overall road safety climate in Victoria, information on compensation claims for medical treatment after being hit by vehicles was obtained from the Transport Accident Commission (TAC). Insurance of motor vehicles with TAC is compulsory. Excluding fatalities, for which no subdivision into head or other injuries was available, Fig. 1 shows the percentage of claims classified as concussion or serious head injury (skull fracture or brain injury), for pedestrians and cyclists in three age groups, the year before and the first two years of the helmet law. Children suffered the highest percentage of head injuries, followed by teenagers and then adults. In general, a smaller percentage of cyclists' claims involved a head injury than pedestrians of the same age group, both before and after the bicycle helmet law. For all groups, the percentage of claims involving a head injury declined steadily from the pre law year to first and second years of the law. The greatest decrease was for child pedestrians where head injuries declined from 18.3% of all claims to 10.7%.

Cameron et al. (1994) ignored the general trend and interpreted the decline for cyclists purely as a consequence of increased helmet wearing. However, a similar trend for child pedestrians and cyclists was apparent in data from 1980–1985, a time when relatively few cyclists wore helmets. Figure 2 shows the percentage of head injuries in claims for most severe injuries to the Motor Accidents Board, the predecessor of TAC, for pedestrians and cyclists aged 0–16 from 1980–1985. The correlation between the head injury percentages is 0.94, statistically significant with $p < 0.02$. Similar trends of declining head injuries have been reported elsewhere. For example, for head injuries in children attending hospitals in Queensland before helmet laws were enforced, Pitt et al. (1994) commented "the reason for the decrease in bicycle related head injuries is more complex than just increased wearing of helmets." In South Australia, North et al. (1993) noted "We have recently observed an apparent fall in the number of patients suffering from head injury due to road trauma..... The largest drop in patient numbers was observed in *motor cyclists*, falling from an average of 24 per year previously, to only five in 1992." This is unlikely to be related to changed helmet wearing; helmet laws for motor cyclists were enacted more than two decades ago and almost universally respected.

The cause of the common trends in percentage

Table 5. Children's cycling activity and bicycle injuries, Melbourne (VISS injury data)

Year to end June	Proportion of 1990 cycle use (N)	Total cycling injuries, (C)	Total head injuries (H)	Equivalent no of injuries for pre law cycle use	
				All injuries ($=C/N$)	Head injury ($=H/N$)
1990	1.00	809	88	809	88
1991	0.67	628	60	937	90
1992	0.64	604	58	944	91
1993	n/a	633	63		

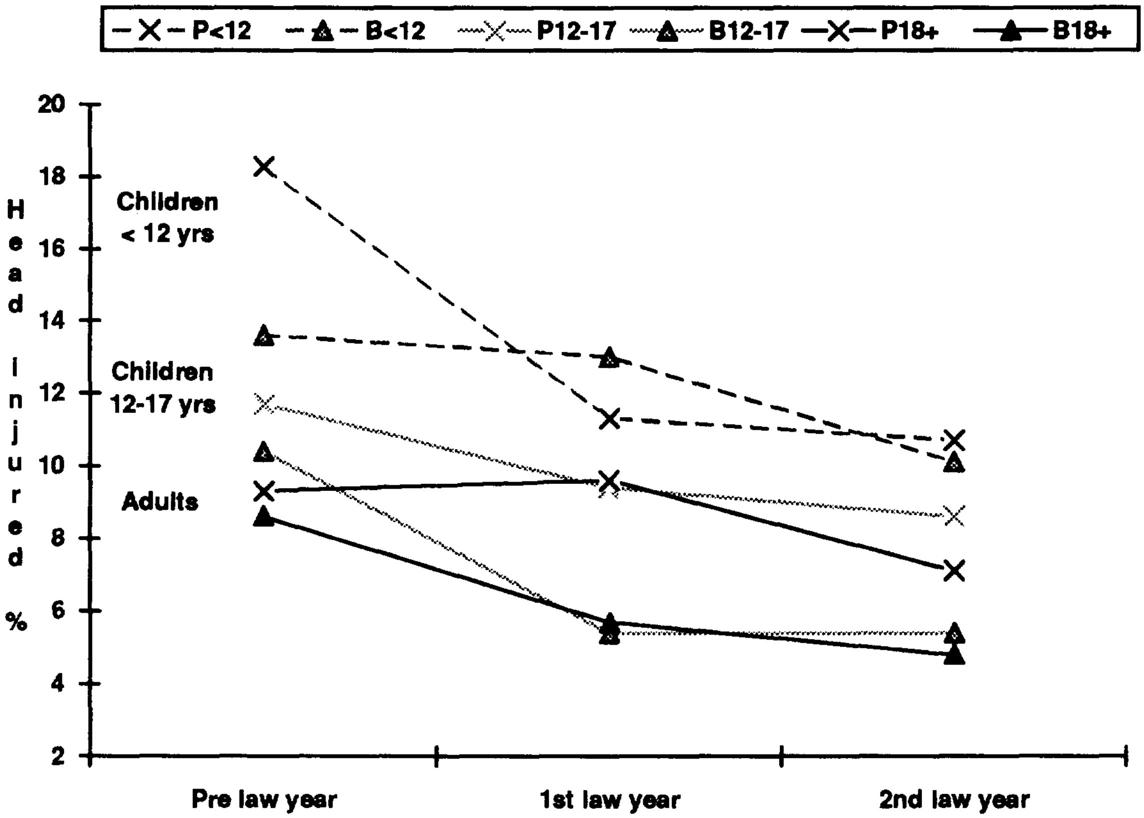

Fig. 1. Percentage of compensation claims involving a head injury by pedestrians (P < 12, P12-17 and P18+) and bicyclists (B < 12, B12-17 and B18+) in Victoria following collision with a motor vehicle, by age of victim—less than 12 years, 12–17 years and over 18s (Transport Accident Commission data).

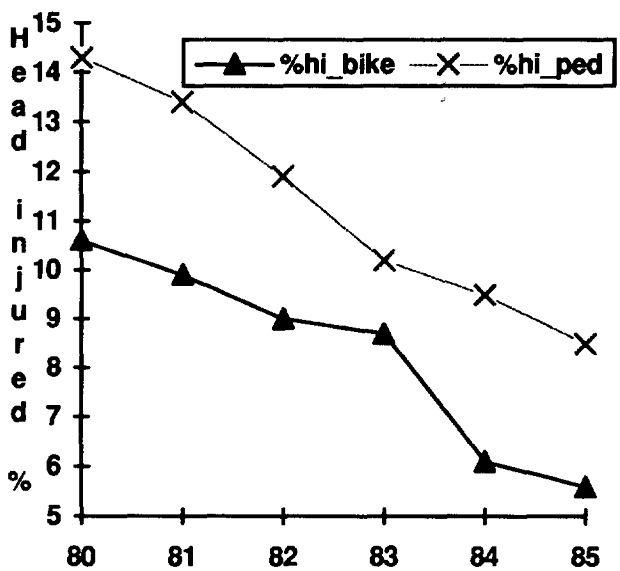

Fig. 2. Percentages of head injured child cyclists and pedestrians, Motor Accidents Authority, 1980–85 (data sourced from SDC 1987).

head injured for pedestrians and cyclists is not fully understood but may relate to impact speed of motor vehicles. Janssen and Wismans (1985) observed a 40% reduction in maximum head acceleration of dummy pedestrians hit by vehicle fronts, compared with reductions of 30%, 22% and 5% for chest, pelvis and feet, when vehicle impact speed was reduced from 40 to 30 km/h. The effect for dummies on bicycles was similar. Maximum head acceleration reduced by 50%, compared with 30%, 16% and 36% for chest, pelvis and feet. Major initiatives directed at drink-driving and speeding were introduced in Victoria in December 1989 and March 1990 (Cameron et al. 1994), and pedestrian fatalities fell by 42% from 159 in 1989 to 92 the following year (ABS 1989, FORS 1990). The proportion of total claims representing severe injuries fell significantly for both pedestrians and cyclists. This suggests a reduction in impact speeds and hence head accelerations and proportion of victims with head injuries.

Risk of head injury for those involved in accidents

The increased numbers of head and other injuries relative to the amount of cycling suggests that accident rates for cyclists may well have increased after the helmet laws. However, some estimate of the effect of helmets for cyclists involved in an accident may be obtained by comparing the observed changes in helmet wearing with the pre and post law percentages of head injured cyclists. If H and N are the probabilities of a head injury for helmeted and non helmeted cyclists in accidents, h_b and h_a the helmet wearing percentages before and after the law, P_b and P_a before and after percentages of cyclists with head injuries, H and N may be estimated by solving *equations*:

$$h_b H + (100 - h_b) N = P_b$$

$$h_a H + (100 - h_a) N = P_a$$

Results are given in Table 6 for all public hospital admissions of adult and child cyclists in NSW, emergency treatment of child cyclists in Melbourne (VISS 1993) and all public hospital admissions for cycling injuries in Victoria (Cameron et al. 1992). To reduce the effect of trends unrelated to helmet wearing, data for the year immediately prior to the law were compared with the first post law year for all cyclists in Victoria and child cyclists in NSW. NSW hospital data were tabulated by financial years (i.e. from 1 July to the end of June), so financial years 89/90 and 91/92 were used to compare percentages of head injured adult cyclists in NSW, for whom the law was introduced on 1 January 1991.

Estimates from the four datasets are remarkably consistent and indicate a reduced risk of head injury for helmeted cyclists involved in accidents of 24%–32%. As shown in Fig. 1, the percentage of accident victims with head injuries was declining for other road users such as pedestrians, even without the benefit of helmets. For simplicity, the above calculations attribute all reductions in head injury, including the declining trend, to the effect of helmets. They should therefore be considered as maxima for the likely benefits of helmet wearing, rather than realistic values.

One possible criticism of this approach is that the increased helmet wearing did not coincide exactly with the start of the law. However, the lowest estimate of helmet efficacy was for adults in NSW, where the year to end June 1990 was compared with that to June 1992. The 26% adult helmet wearing rate was based on a survey of 5380 cyclists in September 1990, three months after the last pre law record used, at 25 road intersections in Sydney and 15 intersections in rural towns (Smith and Milthorpe 1993). The 81% wearing rate was based on averages from similarly extensive surveys in April 1991 (77% wearing) and 1992 (85% wearing), before and during the post law data collection period from July 1991 to June 1992. In Victoria, wearing rates of 94%, 87% and 89% in primary and secondary schoolchildren and adult commuters were observed in surveys in July 1990, the month the law was introduced (Sullivan 1990), higher than estimates for the whole year. As additional evidence, Fig. 3 compares the total number of TAC injury claims *not* classed as head injuries for cyclists and pedestrians in Victoria. Similar to the fall in percentages head injured, those for pedestrians follow a generally declining trend, consistent with a safer traffic environment from the introduction of speed cameras and more vigorous enforcement of the drink driving laws in December 1989 as part of an intensive and effective road safety campaign (Powles and Gifford 1993). Cyclists' claims not classed as head injury fall dramatically, mirroring the change in helmet wearing. Given observed decreases in numbers of cyclists four times the increases in numbers wearing helmets (Table 4), this strongly suggests a sudden and sustained reduction in cycle use immediately the law was introduced. The clear associations between total numbers of claims not involving a head injury and helmet wearing, but less clear association with percen-

Table 6. Estimates of pre and post law helmet wearing rates from observational surveys, percentages of cyclists with head injury (HI) and percentage reduction in risk of head injury from helmet wearing for all admissions to public hospitals following cycling accidents in NSW and Victoria, and for child cyclists given emergency treatment at VISS hospitals in Melbourne, Victoria

	Admissions NSW hosp <16 years	Admissions NSW hosp 16+ years	Admissions Vic hospitals all ages	Emerg. treat. children Melb. VISS hospitals
%helmeted - pre law	31.5	26.1	30.9	39.2
%helmeted - post law	75.9	81.0	75.2	71.9
%head injured - pre law	29.3	29.9	31.4	10.9
%head injured - post law	25.0	25.7	27.3	9.6
Max %HI reduction - helmets*	29.9	24.0	27.0	32.5
No of cases	2397	1600	2300	1437
Statistical significance†	$p<0.05$	ns	ns	ns

*$100(1-H/N)$ where H and N are HI percentages with and without helmets.
†χ^2 test (see e.g. Moroney 1969).

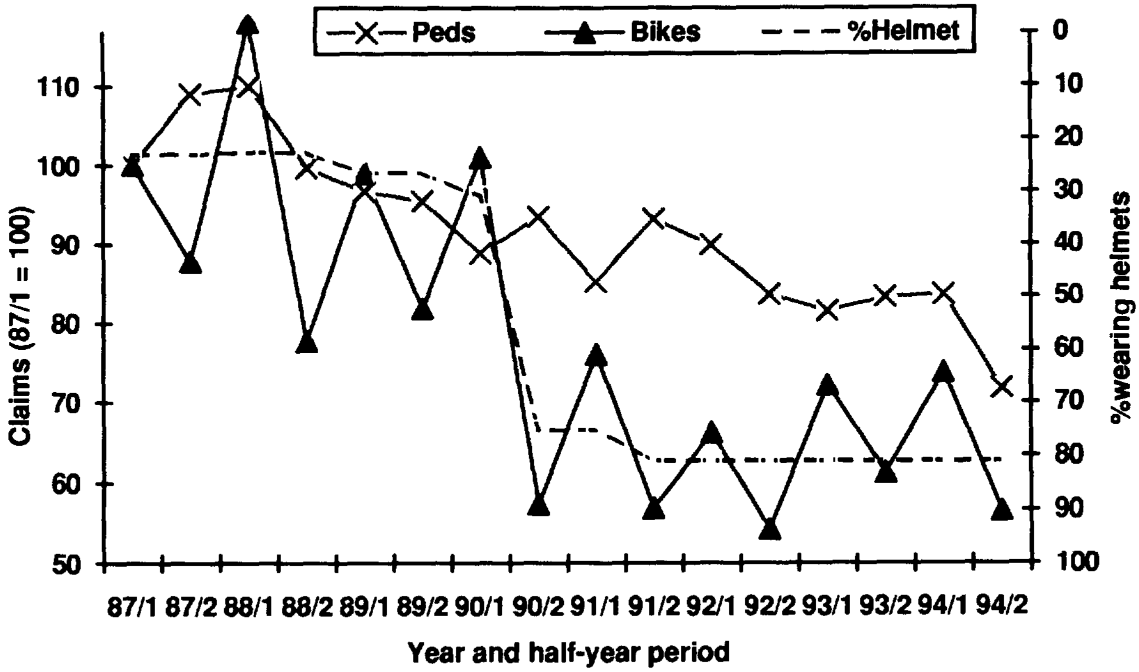

Fig. 3. Relationship between total number of TAC claims *not* involving a head injury for pedestrians (peds) and cyclists (bikes) and helmet wearing by cyclists (%helmet) by year and half year period. Cycle helmet wearing is plotted in reverse order on the right hand scale. Numbers of claims are expressed as a percentage of those in the first half of 1987.

tage of head injured cyclists (Fig. 1) illustrates the most significant effect of the law was not its effect on head injuries but on numbers of cyclists.

DISCUSSION

Numbers of head and other injuries vs numbers of cyclists

Perhaps the most remarkable aspect of the data both from Victoria and NSW is that the decrease in numbers of cyclists was at least as large as the decrease in numbers of head injuries and larger than the total decrease in injuries. This suggests cyclists are now worse off than before the law. One possible explanation is risk compensation. Cyclists feel protected by helmets and so may tend to take more risks. Elliott and Shanahan (1986), for example, reported young people believe "approved helmets would save their heads and lives in the event of a serious accident (with a bus or truck!)" In the US, Rodgers (1988) modelled the effect of increasing helmet use on bicycle fatalities, accounting for the overall road safety climate by fitting pedestrian fatalities as well as other factors as covariates. He commented "the coefficient for HELMET was positive in all equations, and significant in the analysis of deaths. Thus, increased helmet use is associated with an increased fatality rate."

Risk compensation has been documented after the introduction of other road safety measures. For example, Grant and Smiley (1993) concluded that drivers shown the effects of antilock braking systems adapted by driving less safely. In the UK, instead of a predicted 1000 lives saved annually from mandatory seatbelts for drivers and front seat passengers, the Department of Transport's statistical assessors estimated actual savings were between 207 and 459. As well as lower than expected reductions for front seat occupants, there were apparent increases in fatalities above the prevailing trend for cyclists (up 40%) and pedestrians (up 14%) involved in collisions with motor vehicles and in rear seat passengers (up 27%) (Durbin and Harvey 1985).

Another possibility relates to the observation that "most accidents occurred because motorists did not see a cyclist, did not expect to see one, or were not looking in the right place when making turning movements at junctions" (Hudson 1978). In the years before the law, cycling was undergoing a surge in popularity. In NSW, for example, "cycling increased significantly +250% in the 1980s in the Sydney metropolitan area" (Webber 1992) where the majority of the State's population live. In Western Australia (WA), numbers estimated to cycle more than once a week almost doubled from 220,000 to 400,000 (18% to 27% of population; Newman 1992). These substantial increases in cycle use were accompanied by only small changes in the numbers of deaths and serious injuries of cyclists in traffic accidents reported to police (Table 7). This suggests factors which affect motorist awareness of cyclists, including overall numbers of cyclists on the roads, and the general road safety climate play a greater part in cyclist safety than helmet wearing.

For example McLean et al. (1994) studied pedestrian fatalities in Adelaide from 1983–1991 and estimated 61% of fatalities would have been avoided in 60 km/h zones (the normal speed limit for urban and residential areas) if speed limits had instead been 50 km/h and drivers had not exceeded the limit. Given the parallels noted here for accidents in which pedestrians and cyclists were hit by cars, similar benefits would be expected for cyclists. On top of these substantial benefits from introducing and enforcing urban speed limits of 50 km/h, when limits were further reduced from 50 to 30 km/h in a Danish project for 223 km of residential streets, a study of 44 experimental streets estimated a 78% reduction in serious injuries (Engel and Thomsen 1992). Considerable benefits of enforcing speed limits were also noted in the UK, where a reduction of 70% in road deaths was observed when speed cameras were switched on in two pilot projects in West London (Hamer 1994).

Specifically for cyclists, similar conclusions might be drawn from a comparisons of fatality rates in different countries. Hillman (1993) reported "the fatality rate per kilometre cycled in Britain is, respectively, two and a half and three and a half times higher than in the Netherlands and Denmark." This variation in favour of countries where there are substantial numbers of cyclists and adequate provision for their needs demonstrates the effect numbers of cyclists and road safety conditions have on cyclists' safety, again suggesting this has greater importance than helmets. By reducing the numbers of cyclists on the roads, the helmet laws may have also reduced motorist awareness of cyclists and hence contributed to an increased risk of cyclists being hit by vehicles.

Comparison with other estimates of reduced head injury

Though the estimates derived from pre and post law wearing rates and total admissions to public hospitals in NSW and Victoria are lower than some other estimates for helmet wearers involved in accidents, they are reasonably close to the two most recent estimates from Australia. McDermott et al. (1993) considered hospital admissions and, with three times as many helmeted cyclists as Thompson et al. (1989), observed a 25% reduction in head injuries for adult cyclists wearing approved helmets (28.6 vs 38.0%), and a 45% reduction for the under 18s. For cyclists who hit their heads as a result of collisions with motor vehicles, the reduction was 30% (McDermott and Lane 1994). Thomas et al. (1994) considered emergency treatment and observed 19.7% of helmeted child cyclists had head injuries, compared with 32.4% of those not wearing helmets, a 39% reduction. After adjusting for severity of accident and other measures, helmet wearing was estimated to reduce the probability of head injury by 63%. However, this would seem to imply helmet wearers were prone to more severe accidents than non wearers. Both these studies took place before helmet laws were enforced. In reality, a lower protective effect of helmets might be expected in cyclists compelled by law to wear them. Those who choose to wear helmets are more likely to appreciate the need for correct wearing, for example ensuring the chin strap is under tension, that the helmet fits well and is not positioned on the back of the head.

Head vs face injuries

In the US, Sacks et al. (1991) found 32% of cyclists treated in emergency departments had head injuries, compared with 10% in the VISS data. Sacks, however, classed any injury above the neck as a head injury; VISS treat facial injuries (24% of accidents) as a separate category from head injuries. The latter are defined as injuries involving the skull region or brain, including concussion, i.e. the injuries helmets are designed to reduce. VISS investigated facial injuries in the first few months of the law, (Ozanne-Smith and Sherry 1990) and found no decrease. Research in Scandinavia (Hansen and Walløe 1994) found unexpectedly high wearing rates of soft shell helmets in children with facial injuries compared to those injured below the neck (24.1% vs 10.4%, $p<0.0001$) and a similar but non significant trend for hard shelled helmet wearers (27.0% vs 23.0%). In contrast, Thompson et al. (1990b) found "no definite effect on the odds of serious facial injury" but protection against serious injury to the upper face. However, a later paper analysing 364 of the 668 accidents in the same dataset (Thompson et al. 1990a) showed adjustments for age in the 1989 paper on head injuries were probably incorrect. Head injury was found to be more common in young children (83% of cases for 0–4s,

Table 7. Numbers of regular cyclists in Western Australia (WA) compared with reported deaths and serious injuries (DSI) and reported deaths and serious injuries, NSW (From Newman 1992; ABS 1991 and RTA 1993)

Year	1982	1986	1989
No of regular cyclists, WA (thousands)	220	300	400
Reported cyclist DSI, WA	123	172	150
DSI/10,000 regular cyclists, WA	5.6	5.7	3.8
Reported cyclist DSI, NSW	379	400	344

42% for 5–9s, 23% for 10–14s) despite negligible helmet wearing (4% of all under 15s). Not accounting for these differences in head injury rates in the three children's age groups may have biased the findings of the original investigation into head injuries. The method and effect of adjustment for age in the face injury data is not entirely obvious, though age adjustment was stated to account for marked changes in the computed odds ratios.

Both Hansen and Walløe (1994) and Thompson et al. (1990b) observed similar numbers of injuries to the face as other parts of the head. The reality of the prediction that 151,400 out of 181,150 head injuries to US cyclists might be prevented if all cyclists wore helmets (CDC 1995) must therefore be questioned. Based as they were on the definition by Sacks et al. (1991) of head injuries as injuries above the neck, half are likely to have been facial injuries, for which little protection of helmets has been demonstrated. A reality check on the number of head injuries helmets can prevent is also provided by McDermott et al. (1993), and McDermott and Lane (1994). 28.6% of approved helmet wearers over 18 suffered injuries to the head (excluding face); for those hitting their heads after a collision with a motor vehicle, 50% had head injuries. If approved helmets prevented 85% of all such injuries, the rate for non wearers should have been 191% and 333%, not the 38% and 71% actually observed.

Risk of head injury for cyclists and other road users

Figures for the risk of death per million hours of activity (Table 8) were published by Vicroads (1990). These figures were based on travel and fatality data collected by the Federal Office of Road Safety (FORS) a few years earlier, when very few cyclists but almost all motorcyclists wore helmets. The proportions dying of head injury in 1988 were published by FORS (1992). The 46% of cyclists dying from head injury in effect represents the unhelmeted rate; only 3% of those killed in 1988 were helmeted. Because most motor cyclists wear helmets, the overall percentage for motor cyclists, 38%, was little different from that for motor cyclists known to be wearing helmets, 34%. Combining risks and percentages dying from head injury, the risk of dying of head injury per million hours is therefore 0.19, 0.34, 0.17 and 2.9 for cyclists, pedestrians, car occupants and motor cyclists. Hospital statistics for Queensland for 1990–1992, before the bicycle helmet law was enforced, show 11.6, 5.8, 9.4 and 6.2 hospital admissions for head injury for every fatal head injury. Thus per million hours of activity, hospital admissions for head injury are approximately 2.2, 2.0, 1.6 and 18.0 for cyclists, pedestrians, car occupants and motor cyclists (Table 8).

Table 8. Risks per million hour of head injury, derived from fatality rates per million hours (Vicroads 1990), percentages of deaths from head injury (FORS 1992), and ratio of hospital admission for head injury (HI) to death from HI (Queensland Health Department Statistics)

	Cyclist	Pedestrian	M Vehicle occupant	Motor cyclists
Fatalities per million hours* (F)	0.41	0.80	0.46	7.66
%Deaths from head injury (%HID)	46	43	36	38
HI deaths/million hours (=%HID*F/100)	0.19	0.34	0.17	2.9
Hospital admissions for HI per HI death	11.6	5.8	9.4	6.2
Hospital admissions for HI/million hours	2.2	2.0	1.6	18.0

*Average of male and female rates and, for *M* vehicle occupants, driver and passenger rates.

This indicates cycling without a helmet carries very little more risk per hour than driving or other activities. Indeed it is many times safer than riding a motor bike. Risks per unit time seem the most appropriate comparison, since few cyclists undertake the lengths of journeys travelled by car. Indeed, the average cycle trip takes less time than the average car journey (Table 9). Note also, if a child is deterred from cycling, as many appear to have been, a single journey may be replaced by three passenger journeys as the child is driven to the destination then the parent returns home, creating risks not only to the vehicle occupants, but to other road users. It is therefore interesting that, given 17 times more motor vehicle occupants died from head injury in 1988 than cyclists (FORS 1992), and both are subject to similar risks of death from head injury (Table 8), cyclists have been singled out for helmet legislation. Crash tests at 56 km/h of 12 small and 10 medium/large makes of new cars resulted in average head injury coefficients (HIC) of 1307 and 1276 for seatbelted drivers and passengers in small cars and 1269 and 1268 for medium/large cars (Consumers' Association 1994). HIC over 1250 mean brain damage is likely. In circumstances where impact forces are partly controlled by a seatbelt, a helmet may be more effective than when a cyclist is hit by a motorist travelling at

Table 9. Percentage of car and cycle journeys less than 5, 10, 15 and 30 minutes, Australia (from FORS 1988)

	<5 min	<10 min	<15 min	<30 min
Male cyclist	12	41	64	90
Male car driver	6	28	49	78
Female cyclist	12	34	58	87
Female car driver	8	37	60	87

speed. Indeed, excluding cases where wearing status was not known, 80% of cyclists in NSW from 1992–1994 were wearing helmets when killed on the roads (RTA 1992–1994). This proportion is similar to the proportion of cyclists observed wearing helmets (85% and 83% for adults in 1992 and 93 respectively; 76% and 74% for children — Smith and Milthorpe 1993), suggesting helmets are not particularly effective at preventing fatalities when cyclists are hit by cars or trucks.

Costs and deterrents

In addition to the surveys which showed greater reductions in numbers of cyclists than increases in cyclists wearing helmets, evidence of the deterrent of helmet laws on cycling is available from attitude surveys. 325 cyclists in ACT in May 1992, asked "Would you cycle less if helmets became compulsory?" found that 90 (28%) said they would (Curnow 1993). A street survey in the Northern Territory found 20% of cyclists had given up because of the law and 42% said they had reduced their cycling (Mead 1993). In Western Australia (WA), a telephone survey in which adults responded on behalf of themselves and their children found 13% of Perth and 8% of country cyclists had given up or cycled less because of the law (Heathcote and Maisey 1994). When the adult respondents in the telephone survey replied for themselves an estimated 27% of the State's adult population—cyclists and non cyclists—(the equivalent of 64% of current adult cyclists) would cycle more if not legally required to wear a helmet. Such surveys may underestimate the impact of a helmet law, especially in a climate of increasing cycle use, because they do not measure those deterred from starting or increasing their cycling activity. Before the law, cycling in WA was enjoying a tremendous increase in popularity, with cyclists growing at 12% a year in the 80s (Newman 1992). The law saw the start of a decline. One bike hire company, which recorded only two minor injuries in 100,000 hirings, claimed to have lost 90% of its business overnight and within 6 months of the WA helmet law, five cycle shops went bankrupt and bike sales dropped by 70% (Cycling Weekly 1993). Automatic counters installed on two key cyclist bridges over the Swan river recorded an average of 16,326 cycle movements weekly for the three months October to December 1991 (pre law). The same months in the post law years 1992–1994 recorded 13067, 12470 and 10701 cyclist movements per week. Similarly the decline in NSW (Table 1) may be contrasted with the fact that "cycling has increased significantly +250% in the 1980s in the Sydney metropolitan area" (Webber 1992). The true effect of a helmet law on cycling should be defined as the difference between participation after the law and what would have happened without it. If the laws actually reversed the trends of increasing popularity of cycling, their true effects may be far greater than suggested by the simple year to year differences in Table 1 and Table 4 for NSW and Victoria or the above data for WA.

Enforcement of the law was fairly stringent. In Victoria, for example, in the year to June 1991, penalty notices and offence reports for not wearing a bicycle helmet represented 2.6% of all traffic offence notices (King 1993), compared with approximately 1.6% of all vehicle kilometres travelled by bicycle (FORS 1988). In Queensland, bicycle travel represents approximately 2.3% of vehicle kilometres (FORS 1988), but when the helmet law was enforced in 1993, bicycle offence notices shot up to 7.9% of traffic offence notices (King 1993). Thus, per kilometre, infringements for not wearing a bicycle helmet were higher (and in the case of Queensland substantially higher) than all other traffic offences put together—speeding, drink–driving, not wearing seatbelts, careless driving or riding. Yet collision with a motor vehicle increases the probability of head injury 3 to 5 fold (Thomas et al. 1994; Maimaris et al. 1994). In the UK, bike/motor vehicle collisions have been found to account for half of all cyclist head injuries (Maimaris et al. 1994). Indeed, the most serious head injuries generally result from bike/motor vehicle collisions. Examining all cases of brain injury relating to bicycle use in San Diego County, California in 1981, Kraus et al. (1987) reported "15% of those whose injuries involved a motor vehicle had unsatisfactory outcomes in that they died or were discharged with severe or moderate disability or persistent vegetative state. All those whose injuries *did not involve a motor vehicle* had good recovery as measured by the Glasgow Outcomes Scale." To prevent such collisions, traffic laws need to be well enforced both for motorists and cyclists. Even in the third year of the law in Victoria, 86% of all traffic offences by cyclists were instances of not wearing a helmet (Australian Cyclist 1993). This considerable focus on helmet wearing may be diverting police attention from traffic behaviour such speeding, drink-driving, cycling on the wrong side of the road or without lights, which may result in cyclist/motor vehicle collisions and cause the most serious head injuries and for which helmets in any case offer limited protection (Hillman 1993).

For example, 20% of drivers in fatal accidents and 15% in serious injury accidents were over the legal alcohol limit, compared with only 2.5% detected at mobile random breath testing units (RTA 1994). The strong over-representation of alcohol impaired drivers in accident and fatality statistics, compared with random breath tests, demonstrates the hazards of drink-driving and the benefits of measures to minimise it. In contrast, excluding cases where helmet wearing was not known, reported accidents in NSW in the three years since the helmet law show 80% of cyclists killed and 80% of those seriously injured wore helmets at the time (RTA 1992–1994). These proportions are almost identical to wearing rates in street surveys (85% and 83% for adults in 1992 and 93 respectively; 76% and 74% for children—Smith and Milthorpe 1993), indicating non helmeted cyclists appear not to be over-represented in serious injury and fatality statistics—a lack of evidence for the hazards of cycling without a helmet, or benefits of minimising this activity.

Victoria was estimated to have in excess of 2 million cyclists out of a population of 4.4 million (Cameron et al. 1994). For WA, Newman (1992) reported that nearly half the population had cycled in the past year. Thus approximately half the population has been required to buy helmets or give up cycling. Yet 17 times more motorists die of head injury than cyclists (FORS 1992), and little more than twice as many helmets would be required to protect the whole population. Reviewing head and neck injuries, McLean (1987) recommended that "the use of protective hats by car occupants be encouraged" and "arrangements made for the developments of specifications." Riley (1993) suggested bicycle style helmets would probably be suitable, though a purpose designed helmet for car occupants is now available (Australian Cyclist 1994). A helmet law for motorists would therefore require only twice as many helmets a bicycle helmet law, but prevent 17 times as many deaths from head injury without discouraging a healthy, non polluting form of exercise and transport.

Health benefits of cycling

Heart and circulatory diseases are amongst the most common causes or death, yet they are often preventable by regular exercise such as cycling (BMA 1992). In Australia in 1990, 42% of deaths to males were from heart or circulatory disease or stroke. Another 8% were from respiratory disease (ABS 1991). Morris et al. (1990) noted that "compared with those who do not cycle, those who do so at least 25 miles per week"—a commute to work of just 2.5 miles—"halve their risk of heart disease." It has been calculated that if only 20% of non-walk trips were transferred to cycling in the UK, cost savings measured by reductions in the costs of pedestrian injuries, general health care and working days lost would amount to £350 million with total saving to the nation including costs of noise, air pollution, congestion, global warming, road construction and maintenance of £1.3 billion every year (CTC 1993). Hillman (1993) compared the increased longevity from regular exercise by cycling several times a week with estimates of the life-years lost in cycling accidents and concluded life-years gained outweighed those lost by a factor of around 20:1.

Encouraging cycling is therefore likely to save lives and money. Conversely, discouraging cycling may result in more deaths and increased community health costs. Any cost/benefit analysis of helmet laws should include loss of health benefits, increased pollution and cost of alternative transport for those discouraged from cycling. This is particularly true if, as available data from matched surveys has so far shown, the decrease in numbers of cyclists is greater than the increase in numbers wearing helmets.

CONCLUSIONS

Despite the large increases in the percentages of cyclists wearing helmets as a result of the mandatory helmet laws, the proportions of cyclists with head injuries admitted or treated at hospital declined by an average of only 13%. Furthermore, these reductions may not have been due entirely to increased helmet wearing. In Victoria, the percentages of cyclists and pedestrians suffering head injuries when hit by motor vehicles followed similar, reducing trends, which may have been caused by the major road safety initiatives introduced at the same time as the helmet law and aimed at speeding and drink-driving.

In contrast to small reductions in the percentage of head injured cyclists, there was an estimated decline of 36% in child cycle use in Melbourne, where matched pre and post law surveys showed a reduction in numbers of child cyclists 15 times greater than the increase in numbers wearing helmets. In NSW, 36% fewer child cyclists were counted, 2.2 times the increase in child cyclists wearing helmets. Indeed, comparison of counts of cyclists with injury data suggest the overall accident rate may even have increased, either because of increased risk taking by cyclists or reduced driver awareness of cyclists. Strict enforcement of the helmet laws may also have contributed by diverting police attention from other dangerous road user behaviour.

Cycling even without a helmet is beneficial to health and carries very little more risk per hour of activity than driving. Indeed, it is many times safer than riding a motor bike. It is therefore interesting that helmet laws have singled out cyclists as needing head protection. Given the generally accepted need for more exercise and the fact that the increase in numbers wearing helmets was substantially less than the reduction in numbers of cyclists, helmet laws may have adverse implications for the costs of health care to the nation.

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