Peer-reviewed papers

Associations between helmet use and brain injuries amongst injured pedal- and motor-cyclists: A case series analysis of trauma centre presentations

By AS McIntosh[1 2], K Curtis[3 4], T Rankin[3], M Cox[3], TY Pang[5], P McCrory[2 6] and CF Finch[2]
[1]Transport and Road Safety Research, Faculty of Science, the University of New South Wales, Sydney, Australia
[2]Australian Centre for Research into Injury in Sport and its Prevention, Monash Injury Research Institute, Monash University, Melbourne Australia
[3]Trauma Department, St. George Hospital, Sydney, Australia
[4]Sydney Nursing School, University of Sydney, Sydney, Australia
[5]School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, Australia
[6]Centre for Health, Exercise and Sports Medicine, University of Melbourne, Melbourne Australia

Abstract

A retrospective case-series study of pedal- and motor-cyclists presenting to a major metropolitan trauma centre over an 18 month period was undertaken. The injury data were coded according to a number of outcome variables, including intracranial injury of AIS severity ≥ 2. Helmet use was coded. After stratification by rider type, data were analysed to examine the relationships between helmet use and injury using logistic regression. A total of 220 injured motorcycle riders and 137 injured pedal cyclists met the study's inclusion criteria, with 195 motorcycle riders and passengers (88.6%) and 87 pedal cyclists (63.5%) wearing helmets. Helmets were associated with a significant reduction ($p<0.05$) in the likelihood of head and intracranial injury in both rider groups. Associated with helmet use was a reduction in intracranial injury likelihood of 66% for both helmeted motorcycle riders and pedal cyclists. The study is further evidence of the benefits offered by helmets.

Keywords:

Bicycles, Brain Injury, Helmets, Motorcycles

Introduction

The mandatory requirements to wear pedal- and motor-cycle helmets differ greatly between and within countries as do voluntary helmet usage rates, despite strong evidence that helmets are effective in reducing head injury [1-12]. A 2001 meta-analysis of pedal cycle helmet effectiveness by Attewell *et al*. demonstrated that there was a significant 50-60% reduction in the risk of head and brain injury for helmet wearers compared to non-wearers; although, in 2011 Elvik considered this an overestimation [1, 13]. In 2011, new research from Amoros *et al*. identified Odds Ratio (OR) of 0.3 for head (brain and skull) injuries of Abbreviated Injury Scale (AIS) severity 3+ and 0.76 for any head injury associated with pedal cycle helmet use [14]. Regarding motorcycle helmets, the National Highway Traffic Safety Administration estimated that in 2008, helmets saved the lives of 1829 motorcyclists in the USA [15]. Further, the USA data showed that helmets are 37% effective in preventing fatal injuries [15].

In Australia it is mandatory, via road rules and consumer legislation, for both pedal- and motor-cyclists to wear a helmet certified to a Standards Australia standard, respectively, AS/NZS 2063 and AS/NZS 1698. Helmet wearing rates in New South Wales (NSW) based on casualty accident data for pedal cyclists and motorcyclists are 79.4% and 95.9%, respectively [16, 17]. However, actual wearing rates may differ by age, with children and adolescents having lower wearing rates than adults [18, 19]. Importantly, helmet use is one element in a Safe Systems approach for unpowered and powered two-wheelers (pedal- and motor-cyclists). Internationally there appear to be different regional approaches to implementing elements in a Safe System for pedal cyclists. For example, some countries provide cycle-paths for pedal cyclists, but have modest helmet wearing rates, e.g. the Netherlands and Denmark; while others have limited pedal cycle specific infrastructure but have mandatory or high helmet wearing rates, e.g. Australia and New Zealand [20, 21]. Motorcyclists, on the other hand, are not separated from other road users and are exposed to high-energy impacts and related injury risks. The 2010 International Road Traffic and Accident Database

(IRTAD) report noted that in 2008 motorcycles accounted for only 1% of vehicle kilometres in Australia but 20% of motor vehicle user road deaths and 30% of motor vehicle users hospitalised after road crashes [22]. This is part of a worldwide phenomenon that is counter to road safety trends for motor vehicle occupants. In the same year, pedal cyclists accounted for 2% of road user fatalities, down from 3% in 1990 (a reduction from 80 to 27 fatalities) around the time mandatory helmet wearing was introduced in Australia [22].

In 2004-05, pedal cyclists (17.1%) and motorcyclists (18.5%) comprised 36% of the 4178 persons with traumatic brain injury (TBI) as the principal diagnosis due to a transport incident [23]. When the types of TBI's are considered, concussion only cases accounted for 67% of all pedal cyclist TBI's and 68% of all motorcyclist TBI's. A review of NSW Roads and Traffic Authority pedal and motor cycle rider casualty data for the calendar years 2008 and 2009 showed that there were a total of 21 fatalities and 2234 casualty cases for pedal cyclists and 118 fatalities and 4833 casualty cases for motorcycle riders in that state [16, 17]. Only 63.2% of the fatally injured pedal cyclists were reported to have been wearing a helmet compared to 79.5% of the casualty cases. In contrast, 90.8% of the fatally injured motorcycle (riders and passengers) were reported to have been wearing a helmet compared to 96.0% of the casualty cases.

Australian Governments were some of the first in the world to introduce mandatory helmet use laws for both motorcyclists in the 1960's and pedal cyclists in the early 1990s [2]. Current knowledge on helmet performance in relation to head and neck injuries in Australia has stemmed from research work completed on average twenty years ago [24-28]. Some of that research contributed to changes in Australian and New Zealand helmet standards, such as the removal of the resistance to penetration test and lowering of the pass/fail acceleration criterion in the bicycle helmet standard. Since the mid 1990's, however, little in-depth research has been conducted to investigate helmet performance in Australia and assess the test standards applied.

Recently, there has been extensive renewed public debate about the benefits of mandatory pedal-cycle helmet legislation in Australia [29]. A retrospective analysis of hospital admission data around the time mandatory helmet laws were introduced showed that head injury rates for cyclists decreased significantly more than limb injury rates, indicating that mandatory helmet laws were beneficial [29]. Arguments made by some anti-helmet advocates specific to helmet performance include that helmets increase the risk of head and brain injury, in particular diffuse axonal injury (DAI), or at best decrease superficial head and skull injuries but not brain injury [30]. Similar debates about bicycle helmet use are taking place in Europe and North America, and continue to take place in the USA regarding motorcycle helmets [19, 31]. In Asia and Africa, pedal- and motor-cycles constitute an important component of transport systems, and there is interest in improving both helmet wearing rates and identifying helmet designs that are suitable for hot and humid climates whilst still providing protection [11, 12, 32, 33]. With this in mind, and in recognition that the lines between human powered two-wheelers, low powered two-wheelers (motorised bicycles and mopeds) and powered two-wheelers are becoming blurred, it is also of interest to compare and contrast the general performance of two types of helmets.

This paper reports on a retrospective case series study of pedal and motorcyclists presenting to a Level 1 trauma centre in Sydney, NSW. These important data are used to provide an up-to-date profile of head and neck injuries sustained by both helmeted and unhelmeted pedal- and motor-cyclists. The study was conducted to assist with the interpretation of cases investigated as part of a major prospective crash investigation focussing on the performance of current pedal- and motor-cycle helmets. Because of mandatory helmet wearing legislation in Australia, this study provides a unique international opportunity to study the potential role of helmets in preventing head and brain injury and to provide some additional guidance on helmet protection.

Methods

Data for pedal- and motor- cyclist injuries were extracted from the trauma registry of St. George Public Hospital (SGH) in Sydney, a level one trauma centre. The SGH is a 600-bed acute care tertiary referral facility and admits more than 50,000 patients annually. Data are collected prospectively on all major trauma presentations and stored in a purpose built data registry, maintained since 1991. Data are obtained from a number of sources, including: ambulance case sheets, in-patient medical records, and patient interviews. The registry provides comprehensive physiologic data (including Glasgow Coma Scores – GCS) and injury descriptions, as well as limited crash descriptors of certain incident-related factors, including helmet use. Trauma registry entry criteria required the pedal- or motor-cyclist to be in a collision of greater than 30 km/h or to have an altered physiologic state at presentation, eg. GCS less than 14 or multiple fractures (Appendix A).

In this case series study, all pedal- and motor- cyclists who were admitted to SGH for primary treatment of injuries sustained during a road crash, and fulfilling the trauma registry entry criteria during an eighteen-month period between July 2008 and December 2009 were selected. Non-identifiable data were provided for analysis. This study protocol was approved through an institutional ethical review process at the University of New South Wales.

Injuries were coded according to the Abbreviated Injury Scale (AIS) 2005 Revision [34]. The overall injury severity for each cyclist was measured by both the Injury Severity Score (ISS) and the New ISS (NISS) [34]. For each case, the main body region of injury was identified by SGH staff and information on all injuries was recorded. Information included body region, nature of injury (e.g. fracture) and AIS code including severity. Cases were also coded using the following dichotomous indicators, with a focus on head, face and specific intracranial (IC) injuries: concussion; IC injury (including concussion); skull fracture; base of skull fracture; facial fracture; cervical spine fracture or dislocation; upper limb (UL) injury of AIS severity ≥ 2; lower limb (LL) injury of AIS severity ≥ 2; and, trunk (thorax, abdomen, pelvis, lumbar and thoracic spines) injury of AIS severity ≥ 2. Included in the IC injury category were: forms of intracranial haemorrhage (subdural, epidural etc), contusions and diffuse axonal injury. If a case had more than one injury meeting the criterion, e.g. a subdural haemorrhage and concussion, it was counted only once in the category IC injury (including concussion). It is important to note that concussion is not DAI. DAI has a severity of 4 or 5 according to AIS 2005, whereas, concussion is typically AIS 1 or AIS 2, and in cases with loss of consciousness of between one and six hours, is AIS 3.

Statistical analyses were performed using SPSS (Statistical Package for the Social Sciences) Version 20 software. Descriptive statistics were calculated. Logistic regression was used to assess the associations between the three outcome variables head (excluding face) injury as the main region of injury, concussion and intracranial injury (including concussion) and predictor variables helmet use, age, gender, upper limb injury of AIS severity ≥ 2, lower limb injury of AIS severity ≥ 2 and trunk (thorax, abdomen, pelvis, lumbar and thoracic spines) injury of AIS severity ≥ 2 [35]. A backward Wald method was used to include predictor terms in the model. Age was also assessed represented by a dichotomous variable (< median age, ≥ median age). The associations between upper limb injury of AIS severity ≥ 2, lower limb injury of AIS severity ≥ 2 and trunk injury of AIS severity ≥ 2 and helmet use were assessed using logistic regression. For pedal cyclists and motorcycle riders, an independent samples Mann-Whitney U test was applied to assess differences in the distribution of age, GCS, ISS and NISS for helmet wearers and non-wearers and a Pearson Chi-squared test was conducted to assess differences in the distribution of head (excluding the face) AIS injury severities. Statistical significance was set at $p<0.05$.

Results

A total of 220 motorcycle riders, six motorcycle pillion passengers and 137 pedal cyclists met the study's inclusion criteria. Approximately eighty percent of patients wore a helmet at the time of the crash: 195 motorcyclists riders and passengers (88.6%) and 87 pedal cyclists (63.5%).

Demographics

The age distributions for the samples of motorcycle riders and pedal cyclists compared to equivalent NSW state-wide casualty data for a similar time period are shown in Figure 1 [16, 17]. The median age of the 220 motorcycle

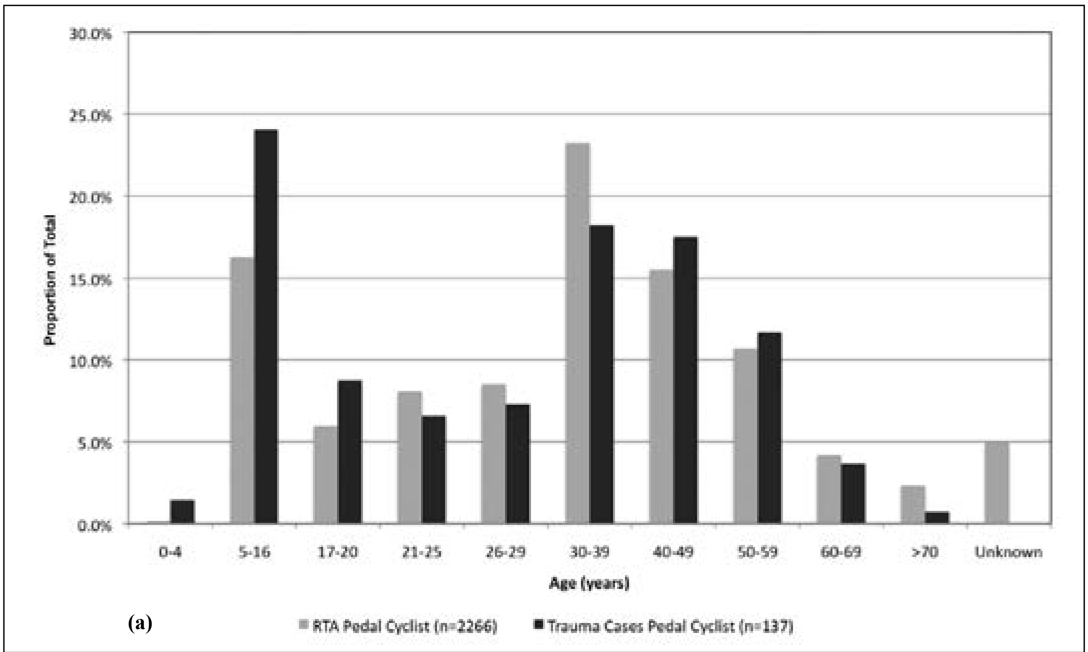

Figure 1. Distribution of (a) pedal cyclists and (b) motorcycle riders by age group

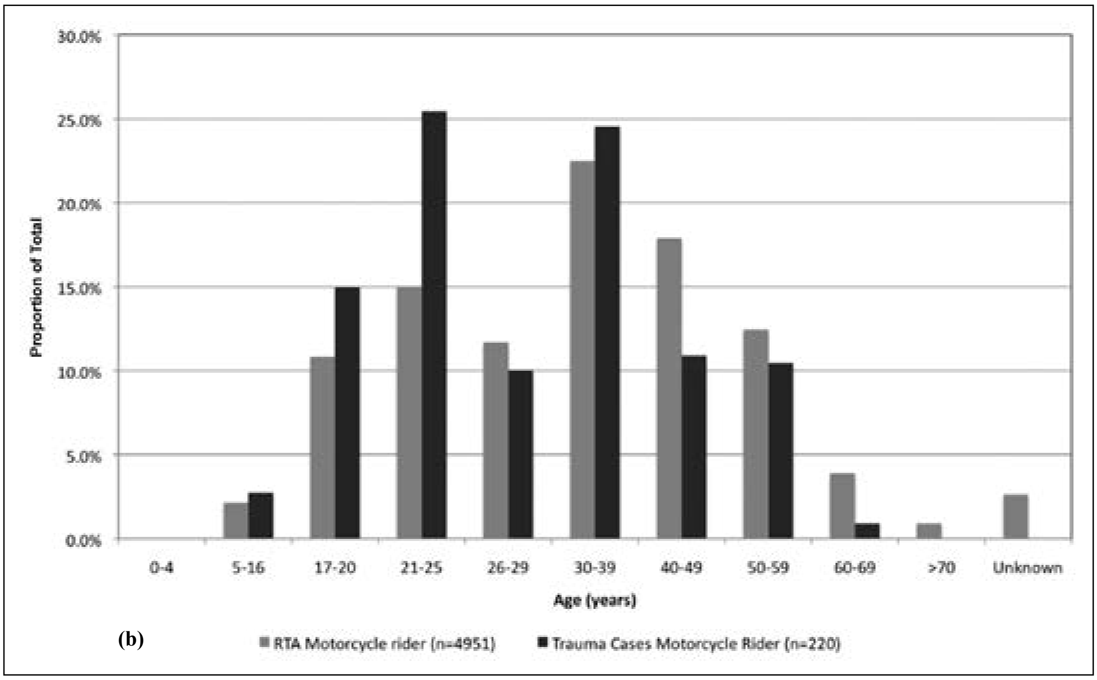

Table 1: Distribution of head and cervical spine injury severity by two-wheeler type and helmet use

		Motorcycle rider (n=220)				Pedal cyclist (n=137)			
		No Helmet		Helmet		No Helmet		Helmet	
	AIS severity	n	%	n	%	n	%	n	%
Maximum AIS for Head (excl. face)	0*	17	57	152	80	20	40	57	66
	1	0	0	0	0	0	0	0	0
	2	8	27	31	16	26	52	28	32
	3-5	5	17	7	4	4	8	2	2
	Total	30	100	190	100	50	100	87	100
Maximum AIS for Cervical Spine	0	29	97	185	97	47	94	85	98
	1	0	0	0	0	0	0	0	0
	2	1	3	3	2	3	6	0	0
	3-5	0	0	2	1	0	0	2	2
	Total	30	100	190	100	50	100	87	100

*An AIS=0 means no injury to that body region riders was 28 years (inter-quartile range (IQR): 22-39). The median age of the 137 pedal cyclists was 30 years (IQR: 16-45). Eighty-three percent (83.2%) of pedal cyclists and 94.1% of motorcycle riders were male. Three of the six motorcycle pillion passengers were female. The median ages for unhelmeted and helmeted motorcycle riders were 22.0 years and 30.0 years, respectively. The median ages for unhelmeted and helmeted pedal cyclists were 21.0 years and 36.0 years, respectively. The age of the unhelmeted pedal cyclists (p=0.010) and motorcycle riders (p=0.000) was significantly lower than their helmeted counterparts.

Profile of head and neck injuries

Due to the small number of motorcycle pillion passengers and the potential differences in related injury mechanisms, only data for motorcycle riders are considered further. Table 1 presents the distribution of head and cervical spine injury severity by cyclist type and helmet use. It can be seen that a higher proportion of helmet wearers have lower severity injuries compared to non-wearers. A Pearson Chi-squared analysis of the AIS distribution by helmet use found a significant difference for maximum head (excluding the face) AIS severity for motorcycle riders (Chi-square=11.71, df=4, p=0.02) and pedal cyclists (Chi-square=12.08, df=4, p=0.017). Non-helmet wearers had the higher severity injuries; for example, the maximum AIS head injury severity for 65.5% of pedal cyclists wearing a helmet was zero (no head injury) compared to 40.0% for non-wearers. Cervical spine injuries were few and not greater than an AIS severity of three for all pedal cyclists and motorcycle riders.

Helmet effectiveness

Table 2 presents the frequencies of discrete injuries by cyclist type and helmet use. Table 3 presents the results of the binary logistic regression for discrete head and brain injuries. There was a significantly lower likelihood of a pedal cyclist experiencing a head injury (Exp(B) = 0.21), concussion (Exp(B) = 0.46), or IC injury (including concussion) (Exp(B) = 0.33) associated with wearing a helmet. The results also show that there was a significantly lower likelihood of a motorcycle rider experiencing a head injury (Exp(B) = 0.35), IC injury (Exp(B) = 0.34), but not concussion, associated with wearing a helmet.

Logistic regression analyses found no significant relationships between helmet use and the following variables: upper limb injury (AIS ≥ 2), lower limb injury (AIS ≥ 2) and trunk injury (AIS ≥ 2).

Because of the low number of cases with fractures (skull, facial, base of skull and cervical spine), no hypothesis testing regarding these specific injuries and helmet use was undertaken. There were six skull or base of skull fractures amongst motorcycle riders and eight amongst pedal cyclists. There were seven facial fractures amongst motorcycle riders and seven amongst pedal cyclists. There were no cases of DAI amongst the pedal cyclists, regardless of helmet use. There were six cases of DAI amongst the motorcyclists, two of whom did not wear a helmet. In each of these cases the adult motorcyclists suffered multiple severe head injuries with a maximum AIS head injury severity of either four or five.

Table 2: Frequencies of cases with specific injuries by cyclist type and helmet use

	Motorcycle rider			Pedal cyclist		
	No Helmet (n=30)	Helmet (n=190)	Total (n=220)	No Helmet (n=50)	Helmet (n=87)	Total (n=137)
Head Injury (as main body location of injury)	8	21	29	30	21	51
Concussion only	8	31	39	25	28	53
IC Injury (including concussion)	13	39	52	30	30	60
Upper Limb (AIS ≥ 2)	7	49	56	8	23	31
Lower Limb (AIS ≥ 2)	4	36	40	4	10	14
Trunk (AIS ≥ 2)	6	27	33	4	6	10

Table 3. Results of binary logistic regression for head injury as main location of injury, concussion only and intracranial injury (including concussion)

Injury		Variables	B	S.E.	Wald	df	Sig.	Exp (B)	95% CI for Exp(B)	
Head Injury	PC	Helmet	-1.56	0.392	15.81 3	1	<0.001	0.21	0.097	0.453
		UL AIS ≥ 2	-1.048	0.522	4.022	1	0.045	0.351	0.126	0.977
		Constant	0.636	0.312	4.161	1	0.041	1.89		
	MC	Helmet	-1.061	0.486	4.762	1	0.029	0.346	0.134	0.898
		UL AIS ≥ 2	-1.281	0.639	4.018	1	0.045	0.278	0.079	0.972
		LL AIS ≥ 2	-1.272	0.764	2.772	1	0.096	0.280	0.063	1.253
		Constant	-0.634	0.44	2.082	1	0.149	0.53		
Concussion only	PC	Helmet	-0.786	0.367	4.601	1	0.032	0.456	0.222	0.934
		Constant	0.041	0.286	0.02	1	0.886	1.042		
	MC	Helmet	-0.86	0.484	3.16	1	0.075	0.423	0.164	1.092
		Median Age	0.67	0.382	3.078	1	0.079	1.954	0.924	4.132
		Constant	-1.186	0.431	7.584	1	0.006	0.306		
Intracranial Injury (including concussion)	PC	Helmet	-1.099	0.37	8.82	1	0.003	0.333	0.161	0.688
		Constant	0.457	0.293	2.427	1	0.119	1.579		
	MC	Helmet	-1.085	0.41	7.013	1	0.008	0.338	0.151	0.754
		Constant	-0.268	0.368	0.53	1	0.467	0.765		

Table 4: Comparison of GCS at admission, ISS and NISS by two-wheeler type and helmet use. The medians and IQRs are presented.

	Motorcycle rider				Pedal cyclist			
	No Helmet		Helmet		No Helmet		Helmet	
	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Initial GCS	15	14-15	15	15-15	15	14-15	15	15-15
ISS	8	4-21	5	2-9	5	3-9	5	2-6
New ISS	9	4-29	5	3-9	6	3-9	6	3-9

Table 4 presents GCS on admission, ISS and NISS for pedal cyclists and motorcycle riders. Mann-Whitney U tests showed that the distributions of GCS (p=0.002), ISS (p=0.004) and NISS (p=0.007) for motorcycle riders were significantly different between helmet wearers and non-wearers. GCS was slightly higher (more normal) for helmeted motorcycle riders and the ISS and NISS were higher (worse) for unhelmeted riders. Mann-Whitney U tests showed that the distribution of GCS for pedal cyclists was significantly different between helmet wearers and non-wearers (p=0.001). GCS was slightly higher for helmeted pedal cyclists. There were no differences in the distribution of ISS and NISS for pedal cyclists by helmet use.

Overall pattern of injuries

The most frequent main body region of injury for all motorcycle riders was the upper limb (28.2%) and for all pedal cyclists the head (37.2%). The shoulder girdle in particular accounted for 16.8% of all motorcyclist injuries. The most frequent main body region of injury for unhelmeted motorcycle riders was the trunk (30.0%) and for helmeted motorcycle riders the upper and lower limbs were equal (29.5%). The most frequent main body region of injury for unhelmeted pedal cyclists was the head (60.0%) and for helmeted pedal cyclists the upper limb (33.3%). Examples of the more severe spectrum of non-head injuries for motorcycle riders were leg amputation, haemothorax and bilateral pulmonary contusions, and for pedal cyclists fractured patella and tibia, fractured ribs, fractured clavicle and haemo-pneumothorax. Table 2 also presents the frequency of upper limb, lower limb and trunk injuries of AIS severity ≥ 2, whether or not they were identified as the main body location of injury.

Ratios of the frequencies of head to upper limb injury as main body region of injury for unhelmeted and helmeted motorcycle riders were 1.33 and 0.39, respectively, and for pedal cyclists 7.5 and 0.72, respectively. Ratios of the frequencies of any intracranial injury (including concussion) to any upper limb injury (AIS severity ≥ 2) for unhelmeted and helmeted motorcycle riders were 1.86 and 0.80, respectively, and for pedal cyclists 3.75 and 1.30, respectively.

Discussion

This study shows that helmets are associated with a large reduction in the likelihood and severity of head injury. In particular, the study provides an evidence base that demonstrates the benefits offered by helmets in reducing brain injury and contradicts the related arguments of anti-helmet advocates.

The age distribution of riders presenting to SGH was similar to the statewide distribution of pedal- and motor-cycle casualties for 2008 and 2009 combined [16, 17]. The proportion of pedal cyclists and motorcycle riders wearing a helmet in this case series was also comparable to the Centre for Road Safety data, but slightly lower than reported in casualty cases in a similar period [16, 17]. Therefore, there is some justification for considering that these results are applicable to a wider population of two-wheelers in NSW. There were differences in the age characteristics of helmeted and unhelmeted pedal- and motor-cyclists, with those wearing helmets tending to be older. This is consistent with the Boufous et al study of pedal cyclists data from the Australian state of Victoria [18].

Results from this study show that wearing a helmet is associated with significant reduction in the likelihood and severity of head and intracranial injuries in injured cyclists attending a major trauma centre, as previously reported in the literature. The gross estimate of the reduction in head injury likelihood for pedal cyclists associated with wearing a helmet was 79% and is similar to earlier assessments [1, 8, 36]. The inclusion criteria provide at least a baseline that indicates that the more severe head injury cases are not being compared to very trivial crashes. By examining specific intracranial injuries, the study also demonstrated that helmets were associated with the prevention and/or reduction in the severity of brain injuries. There was a reduction of intracranial injury by 66% associated with wearing a helmet for both motorcycle riders and pedal cyclists. Because of the claims made by anti-helmet campaigners that helmets cause DAI, it is important to note that no pedal cyclist was diagnosed with DAI [37]. If the claim was made on the erroneous conflation of concussion with DAI, then it must be highlighted that helmeted pedal cyclists had a reduced incidence of concussion. Those motorcyclists diagnosed with DAI suffered severe multiple brain injuries; most likely indicative of the head impact severity. Associated with helmet use was a non-significant decrease in the frequency of concussion for motorcycle riders and a significantly lower likelihood of concussion for pedal cyclists; both around 50%. Although this is a positive result, it also highlights the challenge of preventing equally well both severe head and brain injury and lower severity brain injury, such as concussion, with current helmet designs [38]. The results, and in consideration for the broader incidence of concussion only TBI's in this population, suggest that further development of helmets should include the objective of reducing concussion. This objective should not be achieved at the expense of reducing the protective benefits offered in severe impacts. The study demonstrates that the use of helmets certified to the relevant Australian and New Zealand standards is associated with substantial benefits in terms of head and brain injury reduction.

The nature of the trauma cases analysed in this case series will be biased towards injury to multiple body regions due to the trauma registry selection criteria. The data indicate that injured motorcycle riders, particularly unhelmeted riders, suffered more severe and multiple injuries than pedal cyclists. For example, median NISS scores were nine and five, respectively, for unhelmeted and helmeted motorcycle riders, compared to five and five for unhelmeted and helmeted pedal cyclists. In the absence of a helmet, head injuries were the most frequent injury suffered by pedal cyclists and motorcycle riders suffered most frequently trunk injury. When motorcycle riders were wearing helmets the injury burden shifted to the upper and lower limbs and for pedal cyclists to the upper limb. The results highlight the need to develop better systems for protecting the pedal cyclists and motorcycle riders, including personal protective equipment (PPE) that protects the limbs and trunk. The potential benefits offered by PPE and helmets presents opportunities and challenges for manufacturers and researchers to provide effective products that meet the ergonomic requirements – mobility, weight, thermal comfort – for two-wheelers in a range of climates and riding situations.

Two major limitations of this study are that: the severity of each crash independent of the injury outcome is unknown; and, only injured cyclists were sampled and uninjured cyclists are absent from the data [39]. For example, the head impact speed, the struck object/s, the impact sequence and collision partners are unknown. These data are typically documented poorly or not at all in hospital clinical notes. In order to examine more specific helmet functions an in-depth crash study of helmeted pedal- and motor-cyclists was conducted in parallel to the study reported here. From a biomechanical perspective, a helmeted rider could strike their helmeted head in a crash and due to the performance of the helmet be uninjured and not present to a trauma centre. Therefore, there is a potential bias towards helmeted riders presenting with head injuries as a result of more severe crashes being represented in the sample. The finding of no significant associations between helmet use and upper limb injury (AIS ≥ 2), lower limb injury (AIS ≥ 2) and trunk injury (AIS ≥ 2) is an indication that the helmeted and unhelmeted cyclists were involved in similar severity crashes.

Another limitation is that the sample size is not large enough to consider differences in helmet performance for different age groups and riding patterns (commuter/recreational/sport). The specific type of helmet, full-face, open face, shell or shell-less, was not known and so it was not possible to assess whether the performance differences observed between hard shell and 'foam' pedal cycle helmets in Norway occurred in Australia [40]. However, the majority of pedal-cycle helmets on the Australian market are micro-shell helmets and the shell-less foam helmets or hard shell helmets that were available in the early 1990's in Australia do not appear to be in circulation [26]. Finally, the SGH registry only categorises helmet use as 'yes' or 'no'. If information on whether a helmet was worn were not available in the hospital or ambulance notes, it would most likely have been entered as 'no'. Data on whether a helmet came off during the impact, which is also critical in evaluating its effectiveness, were not available [41].

Notwithstanding these limitations, this study reinforces the importance of helmets in preventing head and brain injuries amongst cases with severe enough injuries to warrant trauma system admission. The study refutes claims made by some that helmets increase the risk of brain injury. The study indicates that if helmet-wearing rates in pedal cyclists increased even further, there would be additional gains in head and brain injury reduction, as observed amongst motorcyclists who have a higher wearing rate. The study highlights the need for programs that increase helmet use amongst younger motorcycle riders and pedal cyclists.

Acknowledgements

This work was conducted by the University of New South Wales, School of Risk and Safety Sciences under funding by an Australian Research Council (ARC) Linkage Grant LP0669480 *Pedal and Motor Cycle Helmet Performance Study*. The project partners are: the Commonwealth Department of Infrastructure and Transport, NSW Roads and Traffic Authority (NSW RTA), Transport Accident Commission Victoria, NRMA Motoring and Services, NRMA-ACT Road Safety Trust and DVExperts International.

Professor Caroline Finch was supported by a National Health and Medical Research Council (NHMRC), Principal Research Fellowship (ID: 565900). The Australian Centre for Research into Injury in Sport and its Prevention (ACRISP) is one of the International Research Centres for Prevention of Injury and Protection of Athlete Health supported by the International Olympic Committee (IOC).

References

1. Attewell RG, Glase K, McFadden M. Bicycle helmet efficacy: a meta-analysis. Accident Analysis & Prevention. 2001;33:345-52.
2. Cameron MH, Vulcan AP, Finch CF, Newstead SV. Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia--An evaluation. Accident Analysis & Prevention. 1994;26(3):325-37.
3. Coben JH, Steiner CA, MIller TR. Characteristics of motorcycle-related hospitalisations: Comparing states with different helmet laws. Accident Analysis & Prevention. 2007;39:190-6.
4. Deutermann W. Traffic Safety Facts 2005: Calculating Lives Saved by Motorcycle Helmets. Washington, D.C.: NHTSA, Department of Transportation, 2005.
5. Houston DJ, Richardson LE. Motorcyclist fatality rates and mandatory helmet-use laws. Accident Analysis & Prevention. 2008;40:200-8.

6. Liu BC, Ivers R, Norton R, Boufous S, Blows S, Lo SK. Helmets for preventing injury in motorcycle riders [Review]. Cochrane Database of Systematic Reviews. 2008;(1). Retrieved January 2009 from The Cochrane Library, Wiley Interscience. Epub 24 October 2007.

7. McDermott FT, Lane JC, Brazenor GA, Debney EA. The effectiveness of bicyclist helmets: A study of 1710 casualties. Journal of Trauma Injury Infection & Critical Care. 1993;34(6):834-45.

8. Thompson DC, Rivara FP, Thompson R. Helmets for preventing head and facial injuries in bicyclists (Review). Cochrane Database of Systematic Reviews. 1999(4).

9. Thompson RS, Rivara FP, Thompson DC. A case-control study of the effectiveness of bicycle safety helmets. The New England Journal of Medicine. 1989;320(21):1471-4.

10. Abu-Zidan FM, Nagelkerke N, Rao S. Factors affecting severity of bicycle-related injuries: The role of helmets in preventing head injuries. Emergency Medicine Australasia. 2007;19(4):366-71.

11. Kyrychenko SY, McCartt AT. Florida's weakened motorcycle helmet law: Effects on death rates in motorcycle crashes. Traffic Injury Prevention. 2006;7(1):55-60.

12. Ouellet JV, Kasantikul V. Motorcycle helmet effect on a per-crash basis in Thailand and the United States. Traffic Injury Prevention. 2006;7(1):49-54.

13. Elvik R. Publication bias and time-trend bias in meta-analysis of bicycle helmet efficacy: A re-analysis of Attewell, Glase and McFadden, 2001. Accident Analysis & Prevention. 2011;43(3):1245-51.

14. Amoros E, Chiron M, Martin J-L, Thélot B, Laumon B. Bicycle helmet wearing and the risk of head, face, and neck injury: a French case–control study based on a road trauma registry. Injury Prevention. 2011; 18: 27-32.

15. The National Highway Traffic Administration. Traffic Safety Facts 2008 Data – Motorcycles DOT HS 811 159. Department of Transportation; 2008.

16. NSW Centre for Road Safety. Road Traffic Crashes in New South Wales, Statistical statement for the year ended 31 December 2008. In: NSW Centre for Road Safety, editor. Sydney: Roads and Traffic Authority; 2008.

17. NSW Centre for Road Safety. Road Traffic Crashes in New South Wales, Statistical statement for the year ended 31 December 2009. In: NSW Centre for Road Safety, editor. Sydney: Roads and Traffic Authority; 2009.

18. Boufous S, Rome LD, Senserrick T, Ivers R. Cycling crashes in children, adolescents, and adults—A comparative analysis. Traffic Injury Prevention. 2011;12(3):244-50.

19. Hewson PJ. Cycle helmets and road casualties in the UK. Traffic Injury Prevention. 2005;6(2):127-34.

20. Pucher J, Buehler R, Seinen M. Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. Transportation Research Part A: Policy and Practice. 2011;45(6):451-75.

21. Pucher J, Dijkstra L. Promoting safe walking and cycling to improve public health: Lessons from the Netherlands and Germany. American Journal of Public Health. 2003;93(9):1509-16.

22. International Traffic Safety Data and Analysis Group. IRTAD Road Safety 2009: Annual Report. OECD/ITF; 2010.

23. Helps Y, Henley G, Harrison JE. Hospital separations due to traumatic brain injury, Australia 2004–05. Adelaide: AIHW, 2008 INJCAT 116.

24. Dowdell B, Long GJ, Ward J, Griffiths M. A study of helmet damage and rider head/neck injuries for crash-involved motorcyclists. RTA Crashlab, 1988.

25. Haworth N, Smith R, Brumen I, Pronk N. Case Controlled Study of Motorcycle Crashes. Canberra: Federal Office of Road Safety, 1997 Contract No.: CR174.

26. McIntosh A, Dowdell B, Svensson N. Pedal cycle helmet effectiveness: A field study of pedal cycle accidents. Accident Analysis & Prevention. 1998;30(2):161-8.

27. McIntosh A, Kallieris D, Mattern R, Svensson NL, Dowdell B, editors. An evaluation of pedal cycle helmet performance requirements. Proceedings of the 39th Stapp Car Crash Conference 1995 8-10 November; San Diego, CA. Warrendale, PA: Society of Automotive Engineers, Inc. SAE Technical Paper No. 952713; 1995.

28. Corner JP, Whitney CW, O'Rourke N, Morgan DE. Motorcycle and bicycle protective helmets: Requirements resulting from a post crash study and experimental research, CR 55. Canberra: Federal Office of Road Safety, 1987 CR 55 Contract No.: CR 55.

29. Walter SR, Olivier J, Churches T, Grzebieta R. The impact of compulsory cycle helmet legislation on cyclist head injuries in New South Wales, Australia. Accident Analysis & Prevention. 2011;43(4):1355-8.

30. Curnow WJ. Bicycle helmets and brain injury. Accident Analysis & Prevention. 2007;39:433-6.

31. European Road Safety Observatory. Pedestrians and Cyclists. European Road Safety Observatory, 2006.

32. Li GL, Li LP, Cai QE. Motorcycle helmet use in southern China: An observational study. Traffic Injury Prevention. 2008;9(2):125-8.

33. Passmore J, Tu NTH, Luong MA, Chinh ND, Nam NP. Impact of mandatory motorcycle helmet wearing legislation on head injuries in Viet Nam: Results of a preliminary analysis. Traffic Injury Prevention. 2010;11(2):202-6.

34. Gennarelli T, Wodzin E, editors. Abbreviated Injury Scale 2005. Barrington, Illinois, USA: Association for the Advancement of Automotive Medicine; 2005.

35. Bland JM, Altman DG. Statistics Notes: The odds ratio. BMJ. 2000;320:1468.

36. Thompson DC, Thompson RS, Rivara FP, Wolf ME. A case-control study of the effectiveness of bicycle safety helmets in preventing facial injury. American Journal of Public Health. 1990;80(12):1471-4.

37. Curnow WJ. Bicycle helmets: Lack of efficacy against brain injury. Accident Analysis & Prevention. 2006;38:833-4.

38. McIntosh AS, Andersen TE, Bahr R, Greenwald R, Kleiven S, Turner M, et al. Sports helmets now and in the future. British Journal of Sports Medicine. 2011;45:1258-65.

39. Finch CF, Ullah S, McIntosh AS. Combining epidemiology and biomechanics in sports injury prevention research: A new approach for selecting suitable controls. Sports Medicine. 2011;41:59-72.

40. Hansen KS, Engesæter LB, Viste A. Protective effect of different types of bicycle helmets. Traffic Injury Prevention. 2003;4(4):285-90.

41. Kasantikul V, Ouellet JV, Smith TA. Head and neck injuries in fatal motorcycle collisions as determined by detailed autopsy. Traffic Injury Prevention. 2003;4(3):255-62.

Appendix A: St George Public Hospital trauma activation criteria