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A population-based case-control study of hospitalisation due to head injuries among bicyclists and motorcyclists in Taiwan

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ABSTRACT

Introduction According to official statistics in Taiwan, the main body region of injury causing bicyclist deaths is the head, and bicyclists are 2.6 times more likely to be fatally injured than motorcyclists. There is currently a national helmet law for motorcyclists but not for bicyclists.
Objectives The primary aim of this study was to determine whether bicyclist casualties have higher odds of head-related hospitalisation than motorcyclists. This study also aims to investigate the determinants of head injury-related hospitalisation among bicyclists and motorcyclists.
Methods Using linked data from the National Traffic Accident Dataset and the National Health Insurance Research Database for the period 2003–2012, this study investigates the crash characteristics of bicyclist and motorcyclist casualties presenting to hospitals due to motor vehicle crashes. Head injury-related hospitalisation was used as the study outcome for both road users to evaluate whether various factors (eg, human attributes, road and weather conditions, vehicle characteristics) are related to hospital admission of those who sustained serious injuries.
Results Among 1 239 474 bicyclist and motorcyclist casualties, the proportion of bicyclists hospitalised for head injuries was higher than that of motorcyclists (10.0% vs 6.5%). However, the multiple logistic regression model shows that, after adjustment of this result for other factors such as helmet use, bicyclists were 18% significantly less likely to be hospitalised for head injuries than motorcyclists (AOR 0.82, 95% CI 0.79 to 0.85). Other important determinants of head injury-related hospitalisation for bicyclists and motorcyclists include female riders, elderly riders, crashes occurring in rural areas, moped riders, riding unhelmeted, intoxicated bicyclists and motorcyclists, unlicensed motorcyclists, dusk and dawn conditions and single-vehicle crashes.
Conclusions Our finding underscores the importance of helmet use in reducing hospitalisation due to head injuries among bicyclists while current helmet use is relatively low.

Strengths and limitations of this study

- This is a comprehensive study using linked data from two datasets which cover 99.9% of the population.
- Our results derived from the linked datasets are more reliable than those using a single database.
- Hospitalisation data are more clinically reliable than injury severity data, which have commonly been used in past studies.
- The study is limited by data that are unavailable from the two datasets such as electronic device use (eg, phone and MP3 players).

INTRODUCTION

Two-wheeled motor vehicle crashes involving bicyclists and motorcyclists have been a serious safety problem in Taiwan with regard to injury severity and frequency. Studies have suggested that head injuries are the primary cause of deaths and hospitalisation among bicyclists and motorcyclists.[1–3] A study reported that, in Taiwan, bicyclists are 2.6 times more likely to be fatally injured than motorcyclists.[4] The main body part that sustained injury resulting in death of these bicyclists was the head (approximately 61%).[5] Head injuries among motorcyclists have become less problematic since the enforcement of the helmet use law for motorcyclists in 1997.[6] Chiu *et al* investigated motorcycle head injuries 1 year after the enforcement of the helmet use law in Taiwan and reported a 33% reduction in head injuries.[6] Helmet use became mandatory for users of electric bicycles in 2016, but not for conventional bicycles.

According to official accident statistics (National Traffic Accident Dataset), the number of motorcycle accidents has been steadily decreasing; however, the number of bicycle accidents has been stably increasing. This is primarily attributable to the increasing popularity of bicycle use. For instance, several bicycle sharing programmes have been implemented in a number of metropolitan cities such as Taipei City and Taichuang City. In addition, the use of electric bicycles and racing bikes, which are widely used for recreational purposes and travelling between cities, has been increasing.

Studies conducted mainly in Asian countries on helmet use and motorcyclist injuries have reported that helmet use and related laws have successfully reduced head injuries, thus reducing fatalities among motorcyclists. Ichiwaka *et al* reported a 41% reduction in head injuries in Thailand 2 years after the implementation of a mandatory helmet use law.[7] A similar reduction in head injuries and fatalities has been reported in Malaysia,[8] Vietnam,[9] USA[3] and Italy[10] after the implementation of helmet use laws. Bicycle helmet use is a means of reducing morbidity and mortality among bike users. Several case-controlled studies have reported an association between helmet use and a decreased rate of head injury and mortality among riders of all ages, with bicycle helmets reducing the risk of head and brain injury by 65–88%.[11] Moreover, Attewell *et al*[12] conducted a meta-analysis of 16 observational studies and reported that bicycle helmets can significantly reduce the risks of head injury by approximately 60%.

Current efforts to increase helmet use in order to prevent head injuries in accidents include campaigns to increase awareness regarding the importance of helmet use, along with advocating helmet use laws. Over the last decades, mandatory bicycle helmet use laws have been implemented in several countries including Australia, New Zealand, Sweden and Canada. A study indicated that helmet use laws act as a deterrent to cycling.[13] Other studies have similarly reported a decline in cycling due to helmet use law.[14,15] In general, a positive effect of mandatory cycle helmet use laws on bicyclist head injuries has been observed in Australia,[16,17] Sweden[18,19] and New Zealand.[20,21]

Taken together, the literature suggests that helmet use and related laws are beneficial for reducing head injuries and fatalities among bicyclists and motorcyclists.

In Taiwan, helmet use is mandatory for motorcyclists but not bicyclists. This leads to an important research question of whether bicyclists involved in motor vehicle crashes (MVCs; a crash that occurs when a vehicle collides with other road users or other stationary objects such as a tree, telegraph pole or traffic island) are more likely than motorcyclists to be hospitalised due to head injuries. The primary aim of this study was to determine whether bicyclist casualties have higher odds of head-related hospitalisation than motorcyclists. Another important hypothesis of the current research is that risk factors that influence head injury-related hospitalisation among bicyclists and motorcyclists may include helmet use, alcohol consumption or license status. This study also aims to investigate the determinants of head injury-related hospitalisation among bicyclists and motorcyclists.

MATERIALS AND METHODS

Data source

Two datasets, police-reported crash data provided by the National Police Agency, Ministry of the Interior and the National Health Insurance Research Database (NHIRD) provided by the Health and Welfare Data Science Centre, Ministry of Health and Welfare, were used in the present study. The National Traffic Accident Dataset is recorded by trained police accident investigators after an accident has been reported to police. The National Traffic Accident Dataset report forms comprise the following three files: accident, vehicle and victim files. A thorough description of the National Traffic Accident Dataset can be found in the study by Chen *et al*.[22]

The Bureau of National Health Insurance (BNHI) in Taiwan implemented the National Health Insurance (NHI) programme on 1 March 1995, and the NHI covers 99% of the residents of Taiwan. The NHIRD comprises outpatient and inpatient claims data of all NHI beneficiaries; all hospitals and clinics are required to report to the BNHI on a monthly basis. The information obtained from the NHIRD can be considered complete and accurate,[23] because the BNHI ensures the accuracy of claims files by performing periodical expert reviews on a random sample for every 50–100 ambulatory and inpatient claims. The NHIRD contains data such as patients' age and gender, admission and discharge dates, care location, hospital level, treatment department, surgical procedures, medical expenditures, diagnosis of disease or injury (in accordance with International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9-CM) N-codes) and cause of injury (in accordance with ICD-9-CM E-codes).

ICD-9-CM N-codes 800–999 that report injury diagnoses were used for extracting injury data. Specifically, the following N-codes were used for extracting head-related injuries: 800, 801, 803, 804, 850–854, 950.1–950.3, 995.55, 959.01, 873.0, 873.1, 870, 871, 918, 802, 872, 873.2–873.9. The encrypted personal identification data in the NHIRD were used to link externally the NHIRD dataset to the National Traffic Accident Dataset. Patients' identification information that is used for linking the two datasets is encrypted by the Health and Welfare Data Science Centre, Taiwan. No individual patient or casualty can be identified, therefore our study was exempted from review by an institutional review board (IRB #201409033).

The flow chart of sample selection from the National Traffic Accident Dataset and the NHIRD is presented in online supplementary appendix 1. The current research examined data for the period 2003–2012. By linking the National Traffic Accident Dataset and the NHIRD, a total of 4 054 668 casualties involved in MVCs were identified. Among the 4 054 668 casualties, 1 998 606 were bicyclists and motorcyclists involved in MVCs (after excluding missing data such as identification and sex data and remaining cases where victims were treated at different times). After removal of the cases where the individuals involved did not receive an injury diagnosis and where patients died within 24 hours, a total of 1 239 474 casualties were either hospitalised or admitted to emergency departments. Among these 1 239 474 casualties, 82 711 were hospitalised for head injuries (treated as cases) and 1 156 763 were hospitalised for other injury types or received emergency treatment only (treated as controls).

Definition of variables

The current study investigates the effects of demographic variables, temporal factors, road and environment characteristics and crash factors on head injuries among bicyclist and motorcyclist casualties. The following demographic data were collected for the casualties: gender; age (<18, 18–40, 41–64 and ≥65 years); blood alcohol consumption (BAC) level (≤0.03% or >0.03%); license status (yes, valid license or no, without a valid license); helmet use (yes or no); and location (highly urbanised area, moderately urbanised area, boomtown, rural area). Vehicle attributes were engine size (≤50 cc or ≥51 cc). Road and environment factors were the following: path type (straight road, curved road or crossroads/roundabout); lighting (daylight, dusk/dawn); road type (provincial highway, county road or other); road surface (dry, wet/slippery); road defect (yes or no); barrier (yes or no); traffic signal (yes or no); separation of traffic direction (yes or no); and traffic island (yes or no). Crash characteristics were the crash type (multiple-vehicle crash or single-vehicle crash) and object type (divided into fixed objects and unfixed objects).

Statistical analysis

The trend of head-related injuries among two-wheeler riders due to MVCs was compared and the difference in hospitalisation percentages was tested with the Mann–Kendall trend test. The distribution of head injury-related hospitalisation and non-head injury-related hospitalisation by a set of variables (eg, human attributes, environmental factors and vehicle characteristics) is reported. χ^2 tests were used to compare patients hospitalised for head-related injuries with those hospitalised for other injuries. Because the dependent variable is binary (hospitalisation for head injuries vs emergency treatment or hospitalisation for other injury types), a logistic regression model was estimated to examine the determinants of hospitalisation for head injuries. A pooled logistic regression model was estimated: the first model of hospitalisation for head injuries included casualty type (bicyclists vs motorcyclists) as one of the variables. In estimating the models, variables with a significance level (P<0.2) in the univariate logistic regression models were then incorporated into the multivariate logistic regression models. The variance inflation factor (VIF) was used to assess multicollinearity among the variables. Only confounding variables were included in the models. Two separate models were employed to examine the determinants of hospitalisation for head injuries among bicyclists and motorcyclists. These two models determined the contributory factors which may differ between bicyclist and motorcyclist casualties.

RESULTS

The results further illustrate the trend of head injuries sustained by bicyclists and motorcyclists who presented to the emergency room or were admitted to hospital (see online supplementary appendix 2). The trend of head injuries appeared to steadily decrease among these two groups: the percentage of head injuries decreased from 16.4% and 10.2% in 2003 to 7.8% and 4.7% in 2012 among bicyclists and motorcyclists, respectively. The decreasing trend was statistically significant according to the Mann–Kendall trend test (P<0.01). Moreover, the risk of sustaining head injuries tended to be higher among bicyclists than among motorcyclists.

Table 1 lists the N-codes for the principal diagnoses of injuries to various body regions resulting in hospitalisation of bicyclists and motorcyclists. Traumatic brain injury (TBI, 29.3%), lower leg and ankle fracture (12.3%) and shoulder and upper arm fracture (9.4%) were the top three injury types among motorcyclists, while TBI (41.4%), lower leg and ankle fracture (10.7%) and forearm and elbow fracture (6.9%) were the top three injury types among bicyclists. The proportion of bicyclists diagnosed with TBI was higher than that of motorcyclists (41.4% vs 29.3%).

Tables 2–4 summarise the human attributes, environmental factors and vehicle characteristics of two-wheeler casualties with head-related injuries occurring between 2003 and 2012. One of the noteworthy results is that the proportion of bicyclists hospitalised for head injuries was higher than that of motorcyclists (10.0% vs 6.5%). The data reported in table 2 confirm that injured motorcyclists (90.99%) had a much higher rate of helmet use than injured bicyclists and that injured bicyclists were less likely to wear a helmet (8.70%) since there is no law requiring helmet use for bicyclists. Other noteworthy results from tables 2–4 are not interpreted here for brevity.

Table 5 lists the crude and adjusted ORs (AORs) of hospitalisation for head injuries among bicyclists and motorcyclists using logistic regression models. Three models were estimated: a pooled model that considered the variable 'vehicle type' as a risk factor and two separate models for bicyclists and motorcyclists. According to the VIF <3, there was no need to be concerned about multicollinearity in the models.

The pooled model revealed that bicyclists were 18% significantly less likely to be hospitalised for head injuries than motorcyclists (AOR 0.82, 95% CI 0.79 to 0.85). Moreover, factors such as being female (AOR 1.08, 95% CI 1.07 to 1.10), age ≥65 years (AOR 1.23, 95% CI 1.19 to 1.28), rural areas (AOR 2.74, 95% CI 2.66 to 2.83), BAC level >0.03% (AOR 2.80, 95% CI 2.73 to 2.87), no use of a helmet (AOR 1.77, 95% CI 1.74 to 1.81), darkness (AOR 1.08, 95% CI 1.03 to 1.12), no separator of divided traffic direction (AOR 1.21, 95% CI 1.19 to 1.24) and single-vehicle crash (AOR 1.75, 95% CI 1.71 to 1.79) were found to be most significantly associated with hospitalisation for head injuries.

The estimated crude and adjusted ORs (AORs) of the two separate models evaluating factors contributing to the hospitalisation of bicyclists and motorcyclists for head injuries were similar to those of the pooled model. Noteworthy results include that female motorcyclists

Table 1 N-codes of principal diagnoses for injuries requiring hospitalisation in two-wheeled vehicle crashes

Total			Motorcyclists			Bicyclists		
N-code	N	%	N-code	N	%	N-code	N	%
Traumatic brain injury	67 464	30.0	Traumatic brain injury	61 826	29.3	Traumatic brain injury	5638	41.4
Lower leg and ankle fracture	27 358	12.2	Lower leg and ankle fracture	25 908	12.3	Lower leg and ankle fracture	1450	10.7
Shoulder and upper arm fracture	20 712	9.2	Shoulder and upper arm fracture	19 839	9.4	Forearm and elbow fracture	939	6.9
Forearm and elbow fracture	16 782	7.5	Forearm and elbow fracture	15 843	7.5	Shoulder and upper arm fracture	873	6.4
Other head, face and neck	15 247	6.8	Other head, face, and neck	14 526	6.9	Hip fracture	743	5.5
Upper leg and thigh fracture	10 975	4.9	Upper leg and thigh fracture	10 528	5.0	Other head, face and neck	721	5.3
Sternum/ribs/pelvis fracture	10 888	4.8	Sternum/ribs/pelvis fracture	10 509	5.0	Spinal fractures	620	4.6
Minor injuries: contusions and abrasions	8640	3.8	Minor injuries: contusions and abrasions	8160	3.9	Minor injuries: contusions and abrasions	480	3.5
Minor injuries: open wounds	7807	3.5	Minor injuries: open wounds	7501	3.6	Sternum/ribs/pelvis fracture	466	3.4
Wrist/hand/finger fracture	6411	2.9	Wrist/hand/finger fracture	6213	2.9	Upper leg and thigh fracture	360	2.6
Other injuries	32 592	14.5	Other injuries	30 416	14.4	Other injuries	1317	9.7

(AOR 1.03) and elderly bicyclists and motorcyclists (AORs 1.92 and1.23, respectively) were more likely to be hospitalised for head injuries. Accidents that occurred in rural areas were associated with a higher risk of hospitalisation for head injuries among bicyclists and motorcyclists (AORs 2.94 and 2.77, respectively). The odds of hospitalisation were higher in riders of mopeds who sustained head injuries than in heavy motorcycle riders (AOR 1.18). Intoxicated bicyclists and motorcyclists had a higher risk of hospitalisation for head injuries (AORs 2.64 and 1.48, respectively). Riding without helmets was found to be a risk factor in both bicyclists and motorcyclists (AORs 1.24 and 1.73, respectively). Motorcyclists travelling without a legal licence were more prone to be hospitalised for head injuries (AOR 1.36). Furthermore, curved roadways and dusk or dawn were associated with an increased risk of hospitalisation for head injuries among bicyclists (AORs 1.16 and 1.28, respectively).

The risk of hospitalisation for head injuries was higher among bicyclists and motorcyclists involved in MVCs that occurred on roadways without separation of traffic direction (AORs 1.09 and 1.21, respectively). Moreover, the risk of hospitalisation for head injuries was 56% and 76% (AORs 1.56 and 1.76, respectively) higher in bicyclists and motorcyclists involved in single-vehicle crashes than in those involved in multi-vehicle crashes.

DISCUSSION

To confirm the research hypotheses, the univariate results suggest that, compared with motorcyclists, bicyclists sustaining head injuries were 59% more likely to be hospitalised. However, the results of multivariate logistic models revealed that, compared with motorcyclists, bicyclists who sustained head injuries had an 18% decreased probability of being hospitalised. After the adjustment of this result for other factors, helmet use appeared to be beneficial in reducing the risks of hospitalisation for head injuries among bicyclists.

The National Traffic Accident Dataset and the NHIRD are both national datasets that cover 99.9% of the population. This is a comprehensive study using the linked data from these two datasets which facilitate the determination of various factors associated with an increased risk of hospitalisation for head injuries among bicyclists and motorcyclists in Taiwan. The conclusions drawn from the current research are therefore more reliable than other studies that solely used a single dataset.

Our finding underscores the importance of helmet use in reducing hospitalisation due to head injuries among bicyclists, in whom current helmet use is relatively low. Also, additional interventions such as education and campaigns should aim to increase riders' awareness of other factors that were found to influence head injury-related hospitalisations. Together with helmet law, these additional interventions can further reduce

Table 2 Characteristics of inpatients with head injury involved in two-wheeled vehicle crashes

	Two-wheeled vehicles					Motorcyclists					Bicyclists				
	Cases		Controls			Cases		Controls			Cases		Controls		
	n	%	n	%	P value	n	%	n	%	P value	n	%	n	%	P value
Total	82711	6.7	1 156 763	93.3		76352	6.5	1 099 277	93.5		6359	10.0	57486	90.0	<0.001
Gender															
Male	48373	7.1	634478	92.9	<0.001	44706	6.9	601593	93.1	<0.001	3667	10.0	32885	90.0	0.523
Female	34338	6.2	522285	93.8		31646	6.0	497684	94.0		2692	9.9	24601	90.1	
Age group (years)															
<18	5123	9.4	49354	90.6	<0.001	3718	10.5	31846	89.5	<0.001	1405	7.4	17508	92.6	<0.001
18–40	38471	5.2	697198	94.8		37955	5.2	689948	94.8		516	6.6	7250	93.4	
41–64	26380	7.9	307322	92.1		24659	7.8	291586	92.2		1721	9.9	15736	90.1	
65+	12737	11.0	102860	89.0		10020	10.4	85874	89.6		2717	13.8	16986	86.2	
Location															
Highly urbanised area	8815	3.6	237868	96.4	<0.001	8218	3.5	227548	96.5	<0.001	597	5.5	10320	94.5	<0.001
Medium urbanised area	23379	5.5	401279	94.5		21743	5.4	383541	94.6		1636	8.4	17738	91.6	
Boomtown	20149	7.0	268552	93.0		18709	6.8	255449	93.2		1440	9.9	13103	90.1	
General township	18924	9.8	174893	90.2		17251	9.5	163844	90.5		1673	13.2	11049	86.8	
Rural area	11444	13.4	73818	86.6		10431	13.2	68556	86.8		1013	16.1	5262	83.9	
Motorcycle engine capacity															
≥51 cc	60411	6.2	907379	93.8	<0.001	60411	6.2	907379	93.8	<0.001	NA	NA	NA	NA	NA
≤50 cc	15941	7.7	191898	92.3		15941	7.7	191898	92.3		NA	NA	NA	NA	
Drunk driving															
No (BAC ≤0.03%)	71070	6.0	1 108 293	94.0	<0.001	64876	5.8	1 051 700	94.2	<0.001	6194	9.9	56593	90.1	<0.001
Yes (BAC >0.03%)	11641	19.4	48470	80.6		11476	19.4	47577	80.6		165	15.6	893	84.4	
Helmet use															
Yes	63575	5.9	1 011 701	94.1	<0.001	63158	5.9	1 006 568	94.1	<0.001	417	7.5	5133	92.5	<0.001
No	19136	11.7	145062	88.3		13194	12.5	92709	87.5		5942	10.2	52353	89.8	
License															
Yes	57613	5.7	952109	94.3	<0.001	57613	5.7	952109	94.3	<0.001	NA	NA	NA	NA	NA
No	16028	11.0	129169	89.0		16028	11.0	129169	89.0		NA	NA	NA	NA	

BAC, blood alcohol concentration; NA, not applicable.

Table 3 Environment characteristics of inpatients with head injury involved in two-wheeled vehicle crashes

	Two-wheeled vehicles					Motorcyclists					Bicyclists				
	Cases		Controls			Cases		Controls			Cases		Controls		
	n	%	n	%	P value	n	%	n	%	P value	n	%	n	%	P value
Path type															
Straight road	34 581	7.9	404 337	92.1	<0.001	31 629	7.7	379 675	92.3	<0.001	2952	10.7	24 662	89.3	<0.001
Curved road	4344	9.1	43 312	90.9		4031	9.0	40 950	91.0		313	11.7	2362	88.3	
Crossroads/roundabout	43 786	5.8	709 114	94.2		40 692	5.7	678 652	94.3		3094	9.2	30 462	90.8	
Lighting															
Daylight	79 618	6.6	1 131 762	93.4	<0.001	73 593	6.4	1 076 250	93.6	<0.001	6025	9.8	55 512	90.2	<0.001
Dusk or dawn	3093	11.0	25 001	89.0		2759	10.7	23 027	89.3		334	14.5	1974	85.5	
Road type															
Provincial highway	7368	10.5	62 628	89.5	<0.001	6833	10.3	59 461	89.7	<0.001	535	14.5	3167	85.5	<0.001
County road	8923	9.6	84 422	90.4		8185	9.3	80 043	90.7		738	14.4	4379	85.6	
Others (township road/private road)	66 404	6.2	1 009 614	93.8		61 318	6.0	959 677	94.0		5086	9.2	49 937	90.8	
Road surface															
Dry	74 774	6.8	1 024 947	93.2	<0.001	69 030	6.6	973 197	93.4	<0.001	5744	10.0	51 750	90.0	0.482
Wet/slippery	7937	5.7	131 816	94.3		7322	5.5	126 080	94.5		615	9.7	5736	90.3	
Road defect															
No	81 560	6.7	1 144 635	93.3	<0.001	75 251	6.5	1 087 538	93.5	<0.001	6309	10.0	57 097	90.0	0.367
Yes	1151	8.7	12 128	91.3		1101	8.6	11 739	91.4		50	11.4	389	88.6	
Barrier															
No	79 862	6.7	1 120 926	93.3	<0.001	73 658	6.5	1 065 006	93.5	<0.001	6204	10.0	55 920	90.0	0.224
Yes	2849	7.4	35 837	92.6		2694	7.3	34 271	92.7		155	9.0	1566	91.0	
Traffic signal															
Yes	25 993	5.7	4 34 048	94.3	<0.001	24 265	5.5	417 304	94.5	<0.001	1728	9.4	16 744	90.6	0.003
No	56 718	7.3	722 715	92.7		52 087	7.1	681 973	92.9		4631	10.2	40 742	89.8	
Separation of traffic directions															
Yes	48 122	6.9	6 48 417	93.1	<0.001	44 113	6.7	613 461	93.3	<0.001	4009	10.3	34 956	89.7	0.002
No	34 589	6.4	508 346	93.6		32 239	6.2	485 816	93.8		2350	9.4	22 530	90.6	
Traffic island															
Yes	25 552	7.6	309 424	92.4	<0.001	23 531	7.4	293 206	92.6	<0.001	2021	11.1	16 218	88.9	<0.001
No	57 159	6.3	847 339	93.7		52 821	6.1	806 071	93.9		4338	9.5	41 268	90.5	

Table 4 Crash characteristics of inpatients with head injury involved in two-wheeled vehicle crashes

	Two-wheeled vehicles					Motorcyclists					Bicyclists				
	Cases		Controls			Cases		Controls			Cases		Controls		
	n	%	n	%	P value	n	%	n	%	P value	n	%	n	%	P value
Crash type															
Multiple vehicle	66457	6.0	1047128	94.0	<0.001	60466	5.7	991673	94.3	<0.001	5991	9.8	55455	90.2	<0.001
Single vehicle	16245	12.9	109635	87.1		15877	12.9	107604	87.1		368	15.3	2031	84.7	
Object type															
Unfixed objects	10829	11.3	84984	88.7	<0.001	10542	11.2	83360	88.8	<0.001	287	15	1624	85.0	0.461
Fixed objects	5416	18.0	24651	82.0		5335	18.0	24244	82.0		81	16.6	407	83.4	
Fixed objects															
Buildings/barriers	1574	14.4	9381	85.6	<0.001	1518	14.3	9072	85.7	<0.001	56	15.3	309	84.7	0.282
Traffic islands/trees/poles/others	3842	20.1	15270	79.9		3817	20.1	15172	79.9		25	20.3	98	79.7	
Unfixed objects															
Animals/pedestrians	2242	7.1	29369	92.9	<0.001	2230	7.1	29134	92.9	<0.001	12	4.9	235	95.1	<0.001
Skidding vehicle	8587	13.4	55615	86.6		8312	13.3	54226	86.7		275	16.5	1389	83.5	

head injury-related hospitalisation for both bicyclists and motorcyclists.

The current research is limited by the fact that mortality data are not explicitly recorded in the NHIRD. Patients die even if they are hospitalised. Unfortunately no such data are available from the NHIRD; these patients are recorded as 'hospitalisations' instead of 'deaths'. Future research may attempt to obtain mortality data that are unavailable from the NHIRD, which would provide additional analysis possibilities and allow more precise model estimation.

Compared with motorcyclists, bicyclists sustaining head injuries were found to have higher risks of hospitalisation; however, after adjustment of this result for other factors in the multivariate analysis, bicyclists were found to have a lower risk of hospitalisation. These results have important implications for policymakers. In 2016, bicycle helmet use became compulsory for electric bicycle users but not for traditional bicycle users in Taiwan. A large-scale nationwide travel survey[24] reported that helmet use was relatively lower among bicyclists (6.8%) than among motorcyclists (82.2%). Because the use of electric bicycles (with higher velocities that may exacerbate crash impacts and injury outcomes) and racing bikes (which have been widely used for recreational purposes and for travelling between cities) has been increasing in recent years, the government should consider encouraging helmets for all bicycles. Further research can therefore be conducted once bicycle helmet use becomes more popular.

In this study, two additional logistic models for bicyclists and motorcyclists were estimated. The results revealed that contributory factors to hospitalisation for head injuries are similar among bicyclists and motorcyclists. For instance, dusk or dawn was associated with a higher risk of hospitalisation for head injuries among both bicyclists and motorcyclists. The findings in this study add to the existing literature on motorcycle and bicycle road safety by concluding that diminished light conditions are associated with accident occurrence[25 26] and also with head injury-related hospitalisation. It seems clear that enhancing conspicuity, in particular in diminished light conditions, may be an effective countermeasure to reduce both the risk of an accident and its consequences.

Our regression models revealed that the risk of hospitalisation is higher among elderly bicyclists and motorcyclists who sustained head injuries. Such a finding is in agreement with that of Ekman *et al*[27] who reported that the risk of head injuries is higher among elderly bicyclists than their younger counterparts. This may be attributable to the fact that, compared with young people, elderly people tend to have more chronic diseases and can have more complications after head injuries, and the hospitalisation rates of elderly people can be higher after an accident.[28 29]

The risk of head injury-related hospitalisation was higher among bicyclists and motorcyclists involved in single-vehicle crashes. This finding may be attributable to higher crash velocities being common in single-vehicle

Table 5 Crude and adjusted ORs of hospitalisation for head injury in two-wheeled vehicle crashes

	Two-wheeled vehicles				Motorcyclists				Bicyclist			
	Crude OR	95% CI	Adjusted OR	95% CI	Crude OR	95% CI	Adjusted OR	95% CI	Crude OR	95% CI	Adjusted OR	95% CI
Vehicle type												
Motorcycle	1.00 (ref)		1.00 (ref)		–		–		–		–	
Bicycle	1.59*	1.55 to 1.64	0.82*	0.79 to 0.85								
Gender												
Male	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Female	0.86*	0.85 to 0.88	1.08*	1.07 to 1.10	0.86*	0.84 to 0.87	1.03*	1.02 to 1.05	0.98	0.93 to 1.03	1.01	0.95 to 1.06
Age (years)												
<18	0.57*	0.57 to 0.58	0.62*	0.60 to 0.64	0.59*	0.58 to 0.60	0.71*	0.68 to 0.74	0.61*	0.56 to 0.67	0.86*	0.77 to 0.96
18–40	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
41–64	1.29*	1.28 to 1.31	0.86*	0.83 to 0.89	1.32*	1.30 to 1.34	0.93*	0.89 to 0.97	0.98	0.93 to 1.04	1.40*	1.29 to 1.51
65+	1.87*	1.83 to 1.90	1.23*	1.19 to 1.28	1.78*	1.74 to 1.82	1.23*	1.18 to 1.29	1.78*	1.69 to 1.88	1.92*	1.80 to 2.06
Location												
Highly urbanised area	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Medium urbanised area	0.74*	0.73 to 0.75	1.49*	1.45 to 1.53	0.74*	0.73 to 0.76	1.51*	1.47 to 1.55	0.78*	0.73 to 0.82	1.60*	1.45 to 1.76
Boomtown	1.07*	1.05 to 1.08	1.78*	1.73 to 1.83	1.07*	1.05 to 1.09	1.81*	1.76 to 1.86	0.99	0.93 to 1.06	1.89*	1.70 to 2.09
General township	1.67*	1.64 to 1.70	2.31*	2.25 to 2.38	1.67*	1.64 to 1.70	2.37*	2.30 to 2.44	1.50*	1.41 to 1.59	2.42*	2.18 to 2.68
Rural area	2.36*	2.31 to 2.41	2.74*	2.66 to 2.83	2.38*	2.33 to 2.43	2.77*	2.68 to 2.87	1.88*	1.75 to 2.02	2.94*	2.63 to 3.29
Motorcycle engine capacity												
≥51 cc	–		–		1.00 (ref)		1.00 (ref)		–		–	
≤50 cc					1.25*	1.23 to 1.27	1.18*	1.15 to 1.20				
Drunk driving												
No (BAC ≤0.03%)	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Yes (BAC >0.03%)	3.75*	3.67 to 3.83	2.80*	2.73 to 2.87	3.91*	3.83 to 4.00	2.64*	2.58 to 2.71	1.69*	1.43 to 2.00	1.47*	1.23 to 1.75
Helmet use												
Yes	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
No	2.10*	2.06 to 2.14	1.77*	1.74 to 1.81	2.27*	2.22 to 2.31	1.73*	1.69 to 1.77	1.40 *	1.26 to 1.55	1.24*	1.12 to 1.38
License												
Yes	–		–		1.00 (ref)		1.00 (ref)		–		–	
No					2.05*	2.01 to 2.09	1.36*	1.33 to 1.39				
Path type												
Straight road	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Curved road	1.43*	1.38 to 1.47	1.01	0.98 to 1.05	1.44*	1.39 to 1.49	1.00	0.96 to 1.03	1.21*	1.07 to 1.36	1.16*	1.03 to 1.32
Crossroads /roundabout	0.71*	0.70 to 0.72	0.90*	0.88 to 0.92	0.71*	0.70 to 0.72	0.90*	0.88 to 0.92	0.84*	0.80 to 0.89	0.94	0.87 to 1.00

Continued

Table 5 Continued

	Two-wheeled vehicles				Motorcyclists				Bicyclist			
	Crude OR	95% CI	Adjusted OR	95% CI	Crude OR	95% CI	Adjusted OR	95% CI	Crude OR	95% CI	Adjusted OR	95% CI
Lighting												
Daylight	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Dusk or dawn	1.76*	1.69 to 1.83	1.08*	1.03 to 1.12	1.75*	1.68 to 1.82	1.05*	1.00 to 1.09	1.56*	1.38 to 1.76	1.28*	1.13 to 1.45
Road type												
Provincial highway	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
County road	1.54*	1.50 to 1.57	0.98	0.94 to 1.01	1.53*	1.49 to 1.57	0.97	0.93 to 1.00	1.59*	1.47 to 1.73	1.06	0.94 to 1.20
Others (township /private road)	0.59*	0.58 to 0.60	0.83*	0.81 to 0.85	0.59*	0.58 to 0.61	0.82*	0.80 to 0.85	0.60*	0.57 to 0.65	0.85*	0.77 to 0.94
Road surface												
Dry	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Wet/slippery	0.83*	0.81 to 0.85	0.85*	0.83 to 0.87	0.82*	0.80 to 0.84	0.84*	0.81 to 0.86	0.97	0.89 to 1.06	1.01	0.93 to 1.11
Road defect												
No	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Yes	1.33*	1.25 to 1.42	0.95	0.89 to 1.01	1.36*	1.28 to 1.44	0.96	0.90 to 1.03	1.16	0.87 to 1.56	1.00	0.74 to 1.36
Barrier												
No	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Yes	1.12*	1.07 to 1.16	0.99	0.95 to 1.03	1.14*	1.09 to 1.18	0.99	0.95 to 1.03	0.89	0.76 to 1.05	0.92	0.78 to 1.09
Traffic signal												
Yes	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
No	1.31*	1.29 to 1.33	1.02	1.00 to 1.04	1.31*	1.29 to 1.33	1.03*	1.01 to 1.05	1.10*	1.04 to 1.17	0.93	0.87 to 1.00
Separation of traffic directions												
Yes	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
No	0.92*	0.90 to 0.93	1.21*	1.19 to 1.24	0.92*	0.91 to 0.94	1.21*	1.19 to 1.23	0.91*	0.86 to 0.96	1.09*	1.02 to 1.16
Traffic island												
Yes	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
No	0.82*	0.80 to 0.83	0.74*	0.73 to 0.76	0.82*	0.80 to 0.83	0.74*	0.73 to 0.76	0.84*	0.80 to 0.89	0.80*	0.75 to 0.86
Crash type												
Multiple vehicle	1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)		1.00 (ref)	
Single vehicle	2.34*	2.29 to 2.38	1.75*	1.71 to 1.79	2.42*	2.38 to 2.47	1.76*	1.72 to 1.79	1.68*	1.50 to 1.88	1.56*	1.38 to 1.76

BAC, blood alcohol concentration.
* represents $p<0.05$

crashes,[30] and helmet use being less common in rural areas where single-vehicle crashes usually occur.[31] Speed management schemes that target all motorised vehicles in general and motorcycles and bicycles (eg, electric bicycles that now in general may travel at more than 25 km/hour[32]) in particular may constitute effective countermeasures for reducing hospitalisation rates for head injuries.

Head injury-related hospitalisation was found to be associated with accidents that occurred in rural areas. This may be because of increasing kinetic energy and greater impact at higher speeds in rural settings.[33 34] In addition, heads are more likely to be exposed without any protection as a result of helmets being less commonly used in rural areas. Such a conjecture is supported by the findings of past studies[35] on motorcycle helmet use which concluded that, compared with riders in cities, riders in rural areas were seven times less likely to wear a helmet. In addition, a national survey administered by the Health Promotion Administration[24] reported that the bicycle helmet use rate in urbanised areas was 1.5 times higher than that in rural areas. Moreover, the requirement of additional time for emergency vehicle response in rural areas and the lower availability of medical resources in such areas[36] predispose people with head injuries to hospitalisation.

The study results showed that the risk of hospitalisation was higher in both bicyclists and motorcyclists who sustained injuries in MVCs on roadways where traffic directions were not separated. This may be because of higher crash velocities at such locations. The road sections may be wide, and speed limits may be higher for locations where the traffic is not divided by any traffic barrier. Therefore, head injuries resulting from accidents in these locations may require hospitalisation. The population-based study was conducted in Taiwan where motorcycles are the dominant transportation mode and there has been a rapid increase in cycling including bikeshare bicycles. The results derived in the current research are therefore generalisable to most other countries where there is a similar traffic composition.

Unanswered questions remain in the current research, including what other factors may affect hospitalisation due to head injuries among bicyclists and motorcyclists. Future research may attempt to obtain variables that are not available from the National Traffic Accident Dataset and the NHIRD. These factors include motorcycle and bicycle types (a greater classification of engine size and electric bicycles), traffic volume, geometric characteristics and the use of electronic devices (eg, telephones and MP3 players), which are increasingly being used when riding.

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