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Comparison of head injury-related hospitalisation between 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 was the head, and bicyclists were 2.6 times more likely to be fatally injured than motorcyclists were.

Objectives

The current research aims to investigate the crash characteristics of hospitalised motorcyclists and cyclists with head injuries.

Methods

Using linked data of the National Traffic Accident Dataset and the National Health Insurance Research Database, this study investigates the crash characteristics of bicyclist and motorcyclist casualties presented 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 (e.g. human attributes, road and weather conditions, and vehicle characteristics) are related to hospital admission of those who sustained serious injuries.

Results

A total of 1239474 motorcyclist and cyclist 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 the 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 were (AOR=0.82; CI=0.79-0.85). Other important determinants of head-injury related hospitalisation for motorcyclists and cyclists include elderly riders, crashes that occurred in rural areas, moped riders, intoxicated motorcyclists and bicyclists, 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.

Keywords: Motorcyclist and bicyclist; Head injury; Hospitalisation; Crashes

Article summary

Strengths and limitations of this study

The Traffic Accident Dataset and the Health Insurance Research Database are both national datasets that cover 99.9% of populations. 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 motorcyclists and bicyclists in Taiwan.

The main limitation of the paper is the data that are not available from the A1A2 police accident dataset and the NHIRD, which would open up possibilities for additional analyses including motorcycle and bicycle types (a greater classification of engine size and electric bicycles and bikesharing programmes that have recently become popular), traffic volume, geometric characteristics, and electronic device use (e.g., phone and MP3 players). These factors may also have a role in injury outcomes and thus hospitalisation rates.

Highlights

- Head injury-related hospitalisation among bicyclists and motorcyclists was investigated.
- The National Traffic Accident Dataset and the National Health Insurance Research Database were combined and analysed.
- Results show that the proportion of bicyclists hospitalised for head injuries was higher than that of motorcyclists (10.0% vs. 6.5%).
- The multiple logistic regression model shows that after adjusting other factors such as helmet use, bicyclists were 18% less likely to be hospitalised for head injuries than motorcyclists.
- Other important determinants of head-injury related hospitalization for motorcyclists and cyclists include elderly riders, crashes that occurred in rural areas, moped riders, intoxicated motorcyclists and bicyclists, unlicensed motorcyclists, dusk and dawn conditions, and single-vehicle crashes.

Introduction

Two-wheel motor vehicle crashes involving motorcyclists and bicyclists 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 motorcyclists and bicyclists[1-3]. A study reported that in Taiwan bicyclists were 2.6 times more likely to be fatally injured than motorcyclists were [4]. The head (approximately 61%) was the main body part that sustained injury resulting in death of these bicyclists[5]. Head injuries among motorcyclists have become less problematic since the enforcement of the helmet use law for motorcyclists in 1997 [6].

According to official accident statistics (Taiwan A1A2 national 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 bike sharing programmes have been implemented in several 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. Chiu et al. (2011) investigated motorcycle head injuries one year after the enforcement of the helmet use law in Taiwan and reported a 33% reduction in head injuries[6]. Furthermore, Ichiwaka et al. (2003) 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], the United States[3], andItaly[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 associate of helmet use with 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. (2001)[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].Others studies have supported this decline in cycling[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].

When reviewed together, literature has suggested that helmet use and related laws are beneficial for reducing head injuries and fatalities among motorcyclists and bicyclists. Following the increasing popularity of bicycle use in recent years in Taiwan, the number of bicycle accidents has steadily increased. In addition, the implementation of several bike-sharing programmes in metropolitan cities such as Taipei City and Taichuang City where bicycle helmets are not provided has presented a safety concern among bicyclists.

The main research objective of the current research was to investigate the crash characteristics of hospitalised motorcyclists and cyclist casualties hospitalised primarily due to head injuries. Hospitalisation for head injuries was considered the study outcome for both road users to evaluate whether various factors such as human attributes, road and weather conditions, and vehicle characteristics are related to hospitalisation of patients with head injuries caused by MVCs. Hospitalisation for head injuries was compared between bicyclists and motorcyclists. In addition, the present paper separately examined factors affecting hospitalisation of motorcyclists and bicyclists primarily for head injuries.

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 Center, Ministry of Health and Welfare, were used in the present study. The police-reported crash data (abbreviated as A1A2) are recorded by trained police accident investigators after an accident has been reported to police. The A1A2 report forms comprise the following three files: accident, vehicle, and victim files. A thorough description of A1A2 can be found in the study of Chen et al. (2016)[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 resident of Taiwan. The NHIRD comprises the 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).

Injury diagnoses are coded according to the ICD-9-CM N-codes 800 to 999. The ICD-9-CM E-codes defining motorcycle or bicycle-related injuries are listed as follows: E800.3, E801.3, E802.3, E803.3, E804.3, E8053, E806.3, E807.3, E810.x-E819.x, E820.6, E821.6, E822.6, E823.6, E824.6, E825.6, E826.1, E826.9, E827.1, E828.1, and E829.1.The encrypted personal identification data in the NHIRD were used to link externally the NHIRD dataset to the A1A2 dataset. Our study was exempted from review by an institutional review board because the encryption of patients' identification information makes it impossible to identify individual patients or casualties (IRB #:201409033).

The flow chart of sample selection from the A1A2 police dataset and the NHIRD is presented in supplementary appendix 1. The current research examined data for the period between 2003 and 2012. By linking the A1A2 crash data and the NHIRD, a total of 4054668 casualties involved in MVCs were identified. Among the 4054668 casualties, 1998606 were motorcyclists and bicyclists 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 1239474 casualties were either hospitalised or admitted to emergency departments. Among these 1239474 casualties, 82711 were hospitalised for head injuries (treated as cases), and 1156763 were hospitalised for other injury types or received emergency treatment only (treated as controls).

Variable definitions

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. Demographic data were collected for the casualties, namely gender (male and female); age (four groups: <18, 18-40, 41-64, and 65 or above); marriage status (married, single, divorced, and others); blood alcohol consumption (BAC) level (<0.03% or >=0.03%); and helmet use (yes or no). Vehicle attributes were the engine size (50cc and51cc or above) and crash partner (bicycle, motorcycle, car or taxi, bus or coach, or heavy goods vehicle). The temporal factor was the crash time (daytime or night time). Road and environment factors were the following variables: location (highly urbanised area, moderately urbanised area, boomtown, rural area), path type (straight road, curved road, or crossroads or roundabout), lighting (daylight, dusk, or dawn);road type (provincial highway, county road, or others);road surface (dry, or wet or slippery);road defect (yes or no);barrier (yes or no);traffic signal (with or without signal);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 which was divided into fixed objects and unfixed objects.

Statistical analysis

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. Furthermore, two separate models were employed to examine the determinants of hospitalisation for head injuries among bicyclists and motorcyclists. These two models determined contributory factors that may be different across bicyclist and motorcyclist casualties.

Results

We further illustrate the trend of head injuries sustained by motorcyclists and bicyclists who presented to the emergency rooms or were admitted to hospitals (see supplementary appendix 2). The trend of head injuries appeared to steadily decrease among these two groups: the percentage of head injuries decreased from 10.2% and 16.4% in 2003 to 4.7% and 7.8% in 2012 among motorcyclists and bicyclists, 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 principal diagnoses of injuries to various body regions resulting in the hospitalisation of motorcyclists and bicyclists. 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. Furthermore, 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 to sustain a TBI was higher than that of motorcyclists (41.4% vs. 29.3%).

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

Total			Motorcyclists			Bicyclists		
N-code	N	%	N-code	N	%	N-code	N	%
Traumatic brain injury	67464	30.0	Traumatic brain injury	61826	29.3	Traumatic brain injury	5638	41.4
Lower leg and ankle fracture	27358	12.2	Lower leg and ankle fracture	25908	12.3	Lower leg and ankle fracture	1450	10.7
Shoulder and upper arm fracture	20712	9.2	Shoulder and upper arm fracture	19839	9.4	Forearm and elbow fracture	939	6.9
Forearm and elbow fracture	16782	7.5	Forearm and elbow fracture	15843	7.5	Shoulder and upper arm fracture	873	6.4
Other head, face, and neck	15247	6.8	Other head, face, and neck	14526	6.9	Hip fracture	743	5.5
Upper leg and thigh fracture	10975	4.9	Upper leg and thigh fracture	10528	5.0	Other head, face, and neck	721	5.3
Sternum/ribs/pelvis fracture	10888	4.8	Sternum/ribs/pelvis fracture	10509	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

Tables 2-4 summarise the human attributes, environmental factors, and vehicle characteristics of two-wheeler casualties with head injuries occurring between 2003 and 2012. One of the noteworthy results includes that the proportion of bicyclists hospitalised for head injuries was higher than that of motorcyclists (10.0% vs. 6.5%). Other noteworthy results from Tables 2-4 are not interpreted here for brevity.

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*	n	%	n	%	*p*	n	%	n	%	*p*
Total	82711	6.7	1156763	93.3		76352	6.5	1099277	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	
Marriage															
Married	35429	7.7	425165	92.3	<0.001	32446	7.5	402059	92.5	<0.001	2983	11.4	23106	88.6	<0.001
Single/divorced/others	46382	6.1	718566	93.9		43159	5.9	685940	94.1		3223	9.0	32626	91.0	
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															
≥51cc	60411	6.2	907379	93.8	<0.001	60411	6.2	907379	93.8	<0.001	NA	NA	NA	NA	NA
≤50cc	15941	7.7	191898	92.3		15941	7.7	191898	92.3		NA	NA	NA	NA	

Drunk Driving															
No (BAC[a] ≤0.03%)	71070	6.0	1108293	94.0	<0.001	64876	5.8	1051700	94.2	<0.001	6194	9.9	56593	90.1	<0.001
Yes (BAC[a]>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	1011701	94.1	<0.001	63158	5.9	1006568	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	

[a]BAC: Blood alcohol concentration

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*	n	%	n	%	*p*	n	%	n	%	*p*
Path Type															
Straight road	34581	7.9	404337	92.1	<0.001	31629	7.7	379675	92.3	<0.001	2952	10.7	24662	89.3	<0.001
Curved road	4344	9.1	43312	90.9		4031	9.0	40950	91.0		313	11.7	2362	88.3	
Crossroads/Roundabout	43786	5.8	709114	94.2		40692	5.7	678652	94.3		3094	9.2	30462	90.8	
Lighting															
Daylight	79618	6.6	1131762	93.4	<0.001	73593	6.4	1076250	93.6	<0.001	6025	9.8	55512	90.2	<0.001
Dusk or dawn	3093	11.0	25001	89.0		2759	10.7	23027	89.3		334	14.5	1974	85.5	
Road type															
Provincial Highway	7368	10.5	62628	89.5	<0.001	6833	10.3	59461	89.7	<0.001	535	14.5	3167	85.5	<0.001
County road	8923	9.6	84422	90.4		8185	9.3	80043	90.7		738	14.4	4379	85.6	
Others(Township road/ Private road)	66404	6.2	1009614	93.8		61318	6.0	959677	94.0		5086	9.2	49937	90.8	
Road surface															
Dry	74774	6.8	1024947	93.2	<0.001	69030	6.6	973197	93.4	<0.001	5744	10.0	51750	90.0	0.482
Wet/Slippery	7937	5.7	131816	94.3		7322	5.5	126080	94.5		615	9.7	5736	90.3	
Road defect															
No	81560	6.7	1144635	93.3	<0.001	75251	6.5	1087538	93.5	<0.001	6309	10.0	57097	90.0	0.367
Yes	1151	8.7	12128	91.3		1101	8.6	11739	91.4		50	11.4	389	88.6	
Barrier															
No	79862	6.7	1120926	93.3	<0.001	73658	6.5	1065006	93.5	<0.001	6204	10.0	55920	90.0	0.224
Yes	2849	7.4	35837	92.6		2694	7.3	34271	92.7		155	9.0	1566	91.0	

Traffic signal															
Yes	25993	5.7	434048	94.3	<0.001	24265	5.5	417304	94.5	<0.001	1728	9.4	16744	90.6	0.003
No	56718	7.3	722715	92.7		52087	7.1	681973	92.9		4631	10.2	40742	89.8	
Separation of traffic directions															
Yes	48122	6.9	648417	93.1	<0.001	44113	6.7	613461	93.3	<0.001	4009	10.3	34956	89.7	0.002
No	34589	6.4	508346	93.6		32239	6.2	485816	93.8		2350	9.4	22530	90.6	
Traffic island															
Yes	25552	7.6	309424	92.4	<0.001	23531	7.4	293206	92.6	<0.001	2021	11.1	16218	88.9	<0.001
No	57159	6.3	847339	93.7		52821	6.1	806071	93.9		4338	9.5	41268	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*	n	%	n	%	*p*	n	%	n	%	*p*
Crash type															
Multiple vehicle	66457	6.0	1047128	94.0	<0.001	60466	5.7	991673	94.3	<0.001	5991	9.8	5981.2	90.2	<0.001
Single vehicle	16245	12.9	109635	87.1		15877	12.9	107604	87.1		368	15.3	352.7	84.7	
Object type															
Unfixed objects	10829	11.3	84984	88.7	<0.001	10542	11.2	83360	88.8	<0.001	287	15	272	85.0	0.461
Fixed objects	5416	18.0	24651	82.0		5335	18.0	24244	82.0		81	16.6	64.4	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	40.7	84.7	0.282
Traffic islands/Trees/Poles/Others	3842	20.1	15270	79.9		3817	20.1	15172	79.9		25	20.3	4.7	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	7.1	95.1	<0.001
Skidding vehicle	8587	13.4	55615	86.6		8312	13.3	54226	86.7		275	16.5	258.5	83.5	

Table 5 lists the crude and adjusted odds ratios (ORs) of hospitalisation for head injuries among motorcyclists and bicyclists 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 motorcyclists and bicyclists. According to the variance inflation factor being <3, there was no need to be concerned about multi-collinearity in the models.

Table 5. Crude and adjusted odds ratios of hospitalization for head injury in two-wheeled vehicle crashed accidents

	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 - 1.64	0.82	0.79 - 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 - 0.88	1.08	1.07 - 1.10	0.86	0.84 - 0.87	1.03	1.02 - 1.05	0.98	0.93 - 1.03	1.01	0.95 - 1.06
Age(year)												
<18	0.57	0.57 - 0.58	0.62	0.60 - 0.64	0.59	0.58 - 0.60	0.71	0.68 - 0.74	0.61	0.56 - 0.67	0.86	0.77 - 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 - 1.31	0.86	0.83 - 0.89	1.32	1.30 - 1.34	0.93	0.89 - 0.97	0.98	0.93 - 1.04	1.40	1.29 - 1.51
65+	1.87	1.83 - 1.90	1.23	1.19 - 1.28	1.78	1.74 - 1.82	1.23	1.18 - 1.29	1.78	1.69 - 1.88	1.92	1.80 - 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 - 0.75	1.49	1.45 - 1.53	0.74	0.73 - 0.76	1.51	1.47 - 1.55	0.78	0.73 - 0.82	1.60	1.45 - 1.76
Boomtown	1.07	1.05 - 1.08	1.78	1.73 - 1.83	1.07	1.05 - 1.09	1.81	1.76 - 1.86	0.99	0.93 - 1.06	1.89	1.70 - 2.09
General township	1.67	1.64 - 1.70	2.31	2.25 - 2.38	1.67	1.64 - 1.70	2.37	2.30 - 2.44	1.50	1.41 - 1.59	2.42	2.18 - 2.68
Rural area	2.36	2.31 - 2.41	2.74	2.66 - 2.83	2.38	2.33 - 2.43	2.77	2.68 - 2.87	1.88	1.75 - 2.02	2.94	2.63 - 3.29
Motorcycle engine capacity												
≥51cc	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
≤50cc					1.25	1.23 - 1.27	1.18	1.15 - 1.20				

	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
Drunk driving												
No (BAC[a] ≤0.03%)	1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)	
Yes (BAC[a]>0.03%)	3.75	3.67 - 3.83	2.80	2.73 - 2.87	3.91	3.83 - 4.00	2.64	2.58 - 2.71	1.69	1.43 - 2.00	1.47	1.23 - 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 - 2.14	1.77	1.74 - 1.81	2.27	2.22 - 2.31	1.73	1.69 - 1.77	1.40	1.26 - 1.55	1.24	1.12 - 1.38
License												
Yes	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
No					2.05	2.01 - 2.09	1.36	1.33 - 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 - 1.47	1.01	0.98 - 1.05	1.44	1.39 - 1.49	1.00	0.96 - 1.03	1.21	1.07 - 1.36	1.16	1.03 - 1.32
Crossroads/Roundabout	0.71	0.70 - 0.72	0.90	0.88 - 0.92	0.71	0.70 - 0.72	0.90	0.88 - 0.92	0.84	0.80 - 0.89	0.94	0.87 - 1.00
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 - 1.83	1.08	1.03 - 1.12	1.75	1.68 - 1.82	1.05	1.00 - 1.09	1.56	1.38 - 1.76	1.28	1.13 - 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 - 1.57	0.98	0.94 - 1.01	1.53	1.49 - 1.57	0.97	0.93 - 1.00	1.59	1.47 - 1.73	1.06	0.94 - 1.20
Others (Township road/Private road)	0.59	0.58 - 0.60	0.83	0.81 - 0.85	0.59	0.58 - 0.61	0.82	0.80 - 0.85	0.60	0.57 - 0.65	0.85	0.77 - 0.94
Road surface												

	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
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 - 0.85	0.85	0.83 - 0.87	0.82	0.80 - 0.84	0.84	0.81 - 0.86	0.97	0.89 - 1.06	1.01	0.93 - 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 - 1.42	0.95	0.89 - 1.01	1.36	1.28 - 1.44	0.96	0.90 - 1.03	1.16	0.87 - 1.56	1.00	0.74 - 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 - 1.16	0.99	0.95 - 1.03	1.14	1.09 - 1.18	0.99	0.95 - 1.03	0.89	0.76 - 1.05	0.92	0.78 - 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 - 1.33	1.02	1.00 - 1.04	1.31	1.29 - 1.33	1.03	1.01 - 1.05	1.10	1.04 - 1.17	0.93	0.87 - 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 - 0.93	1.21	1.19 - 1.24	0.92	0.91 - 0.94	1.21	1.19 - 1.23	0.91	0.86 - 0.96	1.09	1.02 - 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 - 0.83	0.74	0.73 - 0.76	0.82	0.80 - 0.83	0.74	0.73 - 0.76	0.84	0.80 - 0.89	0.80	0.75 - 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 - 2.38	1.75	1.71 - 1.79	2.42	2.38 - 2.47	1.76	1.72 - 1.79	1.68	1.50 - 1.88	1.56	1.38 - 1.76

[a]BAC: Blood alcohol concentration

The pooled model revealed that bicyclists were 18% significantly less likely to be hospitalised for head injuries than motorcyclists were (AOR=0.82; CI=0.79-0.85). Moreover, factors such as the females (CI=1.07-1.10), age 65 or above (CI=1.19-1.28), rural areas (CI=2.66-2.83), BAC level>0.03% (CI=2.73-2.87), no use of a helmet (CI=1.74-1.81), darkness (CI=1.03-1.12), no separator of divided traffic direction (CI=1.19-1.24), and single-vehicle crash(CI=1.71-1.79) were found to be the 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 motorcyclists and bicyclists for head injuries were identical to those of the pooled model. Noteworthy results include that female motorcyclists (AOR=1.03) and elderly motorcyclists and bicyclists (AORs=1.23 and1.92, 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 motorcyclists and bicyclists (AORs=2.77 and2.94, respectively). The odds of hospitalisation were higher in riders of mopeds who sustained head injuries than in heavy-motorcycles riders (AOR=1.18). Intoxicated motorcyclists and bicyclists had a higher risk of hospitalisation for head injuries (AORs=1.48 and2.64, respectively). Riding without helmets was found to be a risk factor in both motorcyclists and bicyclists (AORs=1.73 and1.24, 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 risks of hospitalisation for head injuries among bicyclists (AORs=1.16 and 1.28, respectively).

The risk of hospitalisation for head injuries was higher among motorcyclists and bicyclists involved in MVCs that occurred on roadways without separation of traffic direction (AORs=1.21 and1.09, respectively). Moreover, the risk of hospitalisation for head injuries was 76% and 56% (AORs=1.76 and 1.56, respectively) higher in motorcyclists and bicyclists involved in single-vehicle crashes than in those involved in multi-vehicle crashes.

Discussions

The A1A2 police accident data and the NHIRD provide a reliable data source that facilitates the determination of various factors associated with an increased risk of hospitalisation for head injuries among motorcyclists and bicyclists in Taiwan. The factors were modelled separately to estimate crude ORs. The 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. Our finding here underscores the importance of helmet use among bicyclists, particularly in cities where bike-sharing programmes have been implemented but a helmet is not provided.

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 e-bike (with higher velocities that may exacerbate crash impacts and injury outcomes) and racing bikes (which have been widely used for recreational purpose and travelling between cities) has been increasing in recent years, the government should consider making helmet use mandatory for all bicyclists and not only for users of electric bicycles.

In this study, two additional logistic models for motorcyclists and bicyclists were estimated. The results revealed that contributory factors to hospitalisation for head injuries are similar among motorcyclists and bicyclists. For instance, dusk or dawn was associated with a higher risk of hospitalisation for head injuries among motorcyclists and bicyclists. Our result here adds to existing literature of motorcycle and bicycle road safety by concluding that diminished light conditions are associated not only with accident occurrence [25 26] but also with head injury-related hospitalisation. It seems clear here that enhancing conspicuity, in particularly in diminished light conditions, may be an effective countermeasure to reduce both

accident risk and its consequences.

Our regression models revealed that the risk of hospitalisation is higher among elderly motorcyclists and bicyclists who sustained head injuries. Such a finding is in agreement with that of Ekman et al. (2001)[27], who reported that the risk of head injuries is higher among elderly bicyclists than their younger counterparts. Our study results indicate that the risk of head injury-related hospitalisation is higher among elderly motorcyclists and bicyclists. 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 motorcyclists and bicyclists involved in single-vehicle crashes. This finding may be attributable to higher crash velocities being common in single-vehicle crashes, and helmet use being less common in rural areas where single-vehicle crashes usually occur. Speed management schemes that target all motorised vehicles in general and motorcycles and bicycles (e.g., e-bikes that now in general may travel at more than 25 km/h) 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[30 31].In addition, heads are more likely to be exposed without any protection as a result of less common use of helmets in rural areas. Our conjecture is supported by the findings of past studies[32]on motorcycle helmet use that concluded that compared with riders in cities, riders in rural areas were 7 times less likely to wear helmets. In addition, a national survey administrated by the HPA[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[33]predispose people with head injuries to hospitalisation.

Our study results revealed that the risk of hospitalisation was higher in both motorcyclists and bicyclists 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 maybe 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.

Our research certainly has limitations. Data not available from the A1A2 police accident dataset and the NHIRD would open up possibilities for additional analyses including motorcycle and bicycle types (a greater classification of engine size and electric bicycles), traffic volume, geometric characteristics, and electronic device use (e.g., phone andMP3 players). These factors may also have a role in injury outcomes and thus hospitalisation rates.

What is already known on this subject?

The main body region of injury causing bicyclist deaths was the head, and bicyclists were 2.6 times more likely to be fatally injured than motorcyclists were in Taiwan.

What this study adds

Univariate logistic models revealed that compared with motorcyclists, bicyclists were 59% more likely to be hospitalised for head injuries.

After adjustment for other factors including helmet use in the multivariate logistic analysis, bicyclists who sustained head injuries were 18% less likely to be hospitalised than motorcyclists were.

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Pai CW contributes to data analysis, interpretation of the data, and final approval of the version to be published.

Chen YC contributes to data analysis, and final approval of the version to be published.

Lin HY contributes to conception of the work, critically review the manuscript, and final approval of the version to be published.

Chen PL contributes to the design of the work, data analysis, interpretation of the data, drafting the manuscript and final approval of the version to be published.

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No additional data available.

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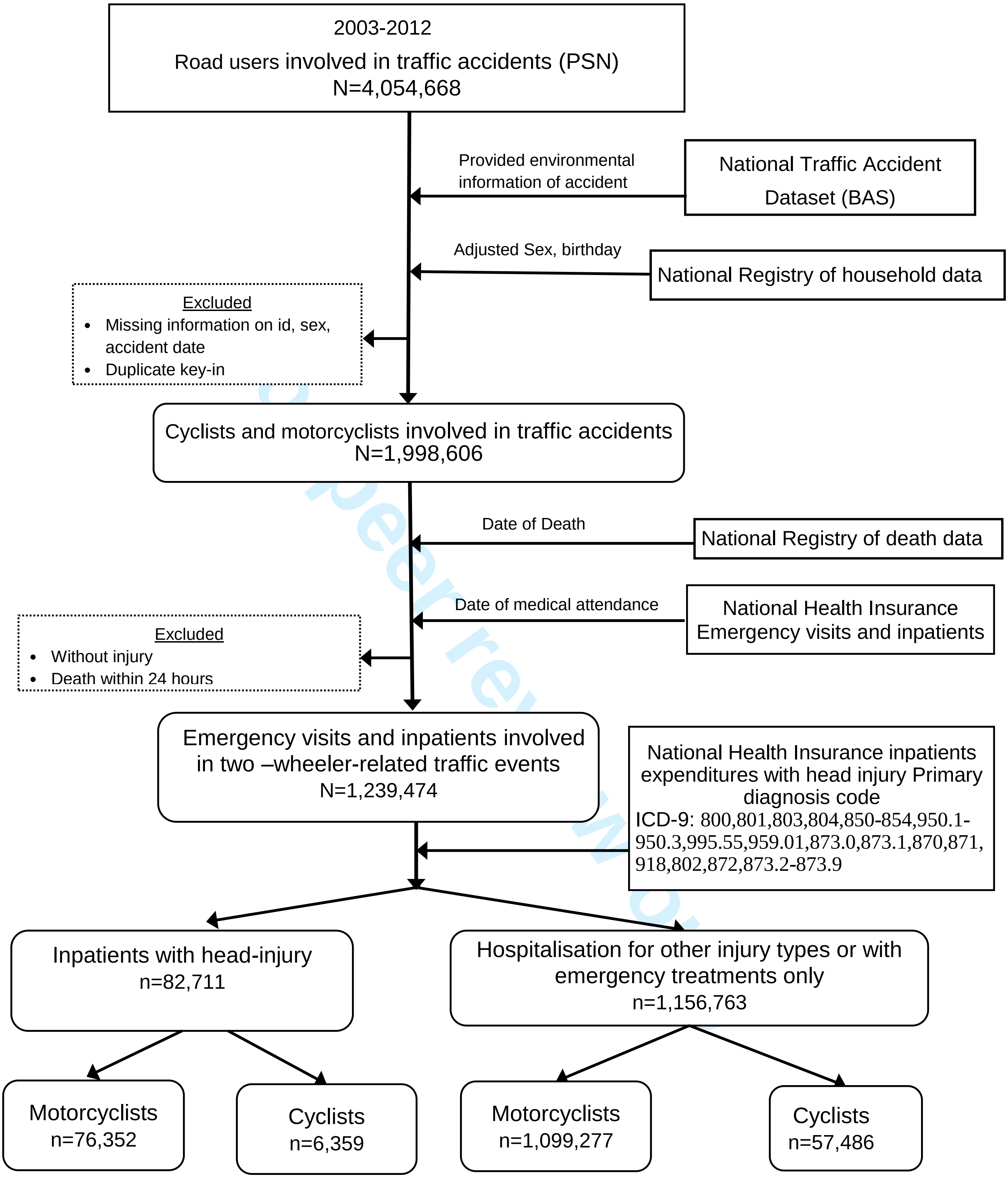
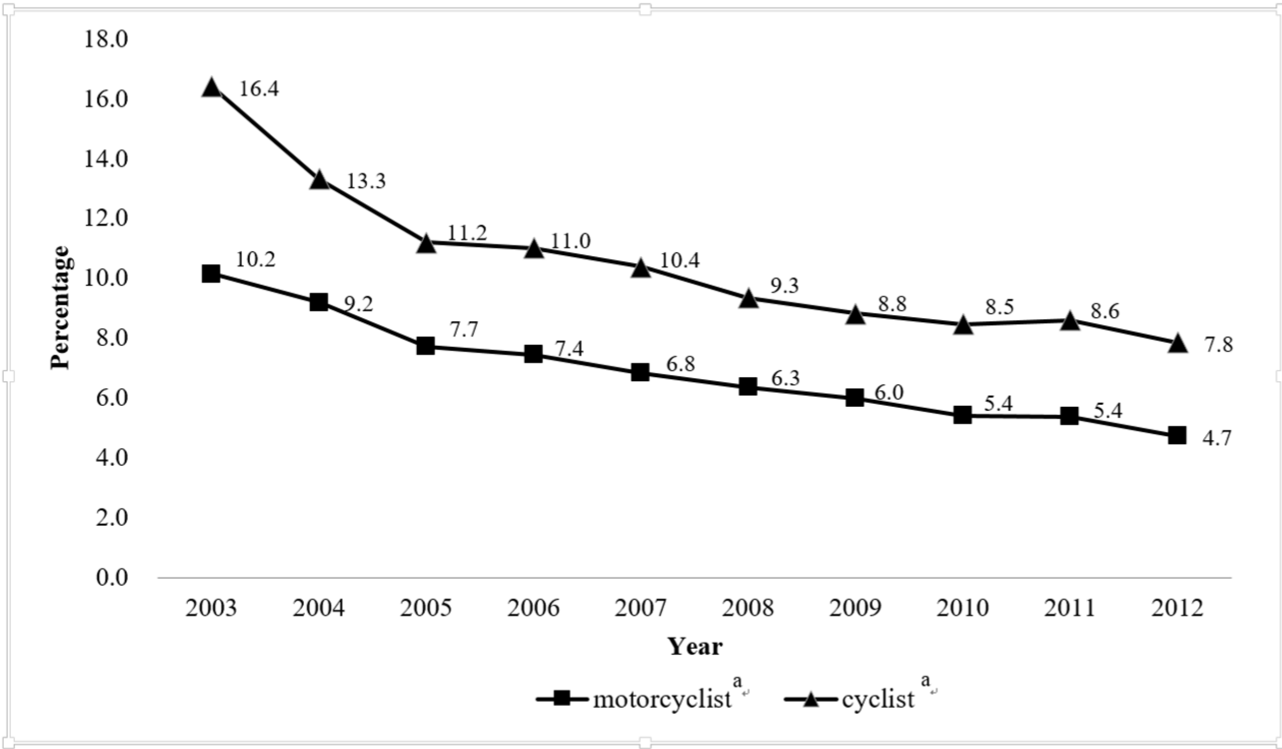


Appendix 1. Study flow diagram



Appendix 2. Trend of head injuries among two-wheeler riders involved in all emergency and inpatient visits for two-wheeler traffic accidents.

[a] :significantly decreasing according to the Mann-Kendall trend test

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-8
Objectives	3	State specific objectives, including any prespecified hypotheses	8
Methods			
Study design	4	Present key elements of study design early in the paper	9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	9-11
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	10-11
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	11-12
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9-12
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	10-11
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	10-11
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking	10-11

account of sampling strategy	
(*e*) Describe any sensitivity analyses	N/A

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8-9
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	Appendix 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	8
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	*8-9, 11*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	19-24
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	24-25
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	27
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	25-27
Generalisability	21	Discuss the generalisability (external validity) of the study results	N/A
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	28

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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

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

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Abstract

Introduction

According to official statistics in Taiwan, the main body region of injury causing bicyclist deaths was the head, and bicyclists were 2.6 times more likely to be fatally injured than motorcyclists were. There is currently a national helmet law for motorcyclists but not for cyclists.

Objectives

The primary aim of this study was to determine whether cyclist casualties, compared with motorcyclists, have higher odds of head-related hospitalisation. This study also aims to investigate the determinants of head-injury related hospitalisation among bicyclists and motorcyclists, respectively.

Methods

Using linked data of the National Traffic Accident Dataset and the National Health Insurance Research Database for the period between 2003 and 2012, this study investigates the crash characteristics of bicyclist and motorcyclist casualties presented 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 (e.g. human attributes, road and weather conditions, and vehicle characteristics) are related to hospital admission of those who sustained serious injuries.

Results

A total of 1239474 motorcyclist and cyclist 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 the 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 were (AOR=0.82; CI=0.79-0.85). Other important determinants of head-injury related hospitalisation for motorcyclists and cyclists include female riders, elderly riders, crashes that occurred in rural areas, moped riders, riding unhelmeted, intoxicated motorcyclists and bicyclists, 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.

Keywords: Motorcyclist and bicyclist; Head injury; Hospitalisation; Crashes

Strengths and limitations of this study

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

Introduction

Two-wheeled motor vehicle crashes involving motorcyclists and bicyclists 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 motorcyclists and bicyclists[1-3]. A study reported that in Taiwan bicyclists were 2.6 times more likely to be fatally injured than motorcyclists were[4]. The head (approximately 61%) was the main body part that sustained injury resulting in death of these bicyclists[5]. Head injuries among motorcyclists have become less problematic since the enforcement of the helmet use law for motorcyclists in 1997[6].

According to official accident statistics (the 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 bike sharing programmes have been implemented in several 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. (2003) 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], the United States[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 associate of helmet use with 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. (2001)[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%.

Chiu et al. (2011) investigated motorcycle head injuries one 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.

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]. Others studies have supported this decline in cycling[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].

When reviewed together, literature has suggested that helmet use and related laws are beneficial for reducing head injuries and fatalities among motorcyclists and bicyclists. In addition, the implementation of several bike-sharing programmes in metropolitan cities such as Taipei City and Taichuang City where bicycle helmets are not provided has presented a safety concern among bicyclists.

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

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 Center, 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 National Traffic Accident Dataset can be found in the study of Chen et al. (2016)[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 resident of Taiwan. The NHIRD comprises the 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 ranging from 800 to 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 Center, Taiwan. No individual patient or casualty can be identified and 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 supplementary appendix 1. The current research examined data for the period between 2003 and 2012. By linking the National Traffic Accident Dataset and the NHIRD, a total of 4054668 casualties involved in MVCs were identified. Among the 4054668 casualties, 1998606 were motorcyclists and bicyclists 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 1239474 casualties were either hospitalised or admitted to emergency departments. Among these 1239474 casualties, 82711 were hospitalised for head-related injuries (treated as cases), and 1156763 were hospitalised for other injury types or received emergency treatment only (treated as controls).

Variable definitions

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. Demographic data were collected for the casualties, namely gender (male and female); age (four groups: <18, 18-40, 41-64, and 65 or above); blood alcohol consumption (BAC) level (<=0.03% or >0.03%);

license status (yes: with a 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 include the engine size (<=50cc and >=51cc or above). Road and environment factors were the following variables: path type (straight road, curved road, or crossroads/roundabout), lighting (daylight, or dusk/dawn); road type (provincial highway, county road, or others); road surface (dry, or 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 which was divided into fixed objects and unfixed objects.

Statistical analysis

Trend of head-related injuries among two-wheeler riders due to MVCs is compared and the difference in hospitalisation percentages is tested with the Mann-Kendall trend test. Distribution of head-injury related hospitalisation and non head-injury related hospitalisation by a set of variables (e.g., human attributes, environmental factors, and vehicle characteristics) is reported. Chi-square tests are conducted for comparing hospitalised patients (for head-related injuries) with hospitalised ones (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, the variables that have significance level ($p<0.2$) in the univariate logistic regression models were then incorporated into the multivariate logistic regression models. VIF (variance inflation factor) was conducted 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 by bicyclists and motorcyclists. These two models determined contributory factors that may be different across bicyclist and motorcyclist casualties.

Results

We further illustrate the trend of head injuries sustained by motorcyclists and bicyclists who presented to the emergency rooms or were admitted to hospitals (see supplementary appendix 2). The trend of head injuries appeared to steadily decrease among these two groups: the percentage of head injuries decreased from 10.2% and

16.4% in 2003 to 4.7% and 7.8% in 2012 among motorcyclists and bicyclists, 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 principal diagnoses of injuries to various body regions resulting in the hospitalisation of motorcyclists and bicyclists. 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. Furthermore, 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 to sustain a TBI was higher than that of motorcyclists (41.4% vs. 29.3%).

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	67464	30.0	Traumatic brain injury	61826	29.3	Traumatic brain injury	5638	41.4
Lower leg and ankle fracture	27358	12.2	Lower leg and ankle fracture	25908	12.3	Lower leg and ankle fracture	1450	10.7
Shoulder and upper arm fracture	20712	9.2	Shoulder and upper arm fracture	19839	9.4	Forearm and elbow fracture	939	6.9
Forearm and elbow fracture	16782	7.5	Forearm and elbow fracture	15843	7.5	Shoulder and upper arm fracture	873	6.4
Other head, face, and neck	15247	6.8	Other head, face, and neck	14526	6.9	Hip fracture	743	5.5
Upper leg and thigh fracture	10975	4.9	Upper leg and thigh fracture	10528	5.0	Other head, face, and neck	721	5.3
Sternum/ribs/pelvis fracture	10888	4.8	Sternum/ribs/pelvis fracture	10509	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

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 includes that the proportion of bicyclists hospitalised for head injuries was higher than that of motorcyclists (10.0% vs. 6.5%). Other noteworthy results from Tables 2-4 are not interpreted here for brevity.

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*	n	%	n	%	*p*	n	%	n	%	*p*
Total	82711	6.7	1156763	93.3		76352	6.5	1099277	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															
≥51cc	60411	6.2	907379	93.8	<0.001	60411	6.2	907379	93.8	<0.001	NA	NA	NA	NA	NA
≤50cc	15941	7.7	191898	92.3		15941	7.7	191898	92.3		NA	NA	NA	NA	
Drunk Driving															
No (BAC[a] ≤0.03%)	71070	6.0	1108293	94.0	<0.001	64876	5.8	1051700	94.2	<0.001	6194	9.9	56593	90.1	<0.001
Yes (BAC[a]>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	1011701	94.1	<0.001	63158	5.9	1006568	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	

[a]BAC: Blood alcohol concentration

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*	n	%	n	%	*p*	n	%	n	%	*p*
Path Type															
Straight road	34581	7.9	404337	92.1	<0.001	31629	7.7	379675	92.3	<0.001	2952	10.7	24662	89.3	<0.001
Curved road	4344	9.1	43312	90.9		4031	9.0	40950	91.0		313	11.7	2362	88.3	
Crossroads/Roundabout	43786	5.8	709114	94.2		40692	5.7	678652	94.3		3094	9.2	30462	90.8	
Lighting															
Daylight	79618	6.6	1131762	93.4	<0.001	73593	6.4	1076250	93.6	<0.001	6025	9.8	55512	90.2	<0.001
Dusk or dawn	3093	11.0	25001	89.0		2759	10.7	23027	89.3		334	14.5	1974	85.5	
Road type															
Provincial Highway	7368	10.5	62628	89.5	<0.001	6833	10.3	59461	89.7	<0.001	535	14.5	3167	85.5	<0.001
County road	8923	9.6	84422	90.4		8185	9.3	80043	90.7		738	14.4	4379	85.6	
Others(Township road/ Private road)	66404	6.2	1009614	93.8		61318	6.0	959677	94.0		5086	9.2	49937	90.8	
Road surface															
Dry	74774	6.8	1024947	93.2	<0.001	69030	6.6	973197	93.4	<0.001	5744	10.0	51750	90.0	0.482
Wet/Slippery	7937	5.7	131816	94.3		7322	5.5	126080	94.5		615	9.7	5736	90.3	
Road defect															
No	81560	6.7	1144635	93.3	<0.001	75251	6.5	1087538	93.5	<0.001	6309	10.0	57097	90.0	0.367
Yes	1151	8.7	12128	91.3		1101	8.6	11739	91.4		50	11.4	389	88.6	
Barrier															
No	79862	6.7	1120926	93.3	<0.001	73658	6.5	1065006	93.5	<0.001	6204	10.0	55920	90.0	0.224
Yes	2849	7.4	35837	92.6		2694	7.3	34271	92.7		155	9.0	1566	91.0	

Traffic signal															
Yes	25993	5.7	434048	94.3	<0.001	24265	5.5	417304	94.5	<0.001	1728	9.4	16744	90.6	0.003
No	56718	7.3	722715	92.7		52087	7.1	681973	92.9		4631	10.2	40742	89.8	
Separation of traffic directions															
Yes	48122	6.9	648417	93.1	<0.001	44113	6.7	613461	93.3	<0.001	4009	10.3	34956	89.7	0.002
No	34589	6.4	508346	93.6		32239	6.2	485816	93.8		2350	9.4	22530	90.6	
Traffic island															
Yes	25552	7.6	309424	92.4	<0.001	23531	7.4	293206	92.6	<0.001	2021	11.1	16218	88.9	<0.001
No	57159	6.3	847339	93.7		52821	6.1	806071	93.9		4338	9.5	41268	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*	n	%	n	%	*p*	n	%	n	%	*p*
Crash type															
Multiple vehicle	66457	6.0	1047128	94.0	<0.001	60466	5.7	991673	94.3	<0.001	5991	9.8	5981.2	90.2	<0.001
Single vehicle	16245	12.9	109635	87.1		15877	12.9	107604	87.1		368	15.3	352.7	84.7	
Object type															
Unfixed objects	10829	11.3	84984	88.7	<0.001	10542	11.2	83360	88.8	<0.001	287	15	272	85.0	0.461
Fixed objects	5416	18.0	24651	82.0		5335	18.0	24244	82.0		81	16.6	64.4	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	40.7	84.7	0.282
Traffic islands/Trees /Others	3842	20.1	15270	79.9		3817	20.1	15172	79.9		25	20.3	4.7	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	7.1	95.1	<0.001
Skidding vehicle	8587	13.4	55615	86.6		8312	13.3	54226	86.7		275	16.5	258.5	83.5	

Table 5 lists the crude and adjusted odds ratios (ORs) of hospitalisation for head injuries among motorcyclists and bicyclists 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 motorcyclists and bicyclists. According to the variance inflation factor being <3, there was no need to be concerned about multi-collinearity in the models.

Table 5. Crude and adjusted odds ratios of hospitalisation for head injury in two-wheeled vehicle crashed accidents

	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 - 1.64	0.82*	0.79 - 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 - 0.88	1.08*	1.07 - 1.10	0.86*	0.84 - 0.87	1.03*	1.02 - 1.05	0.98	0.93 - 1.03	1.01	0.95 - 1.06
Age(year)												
<18	0.57*	0.57 - 0.58	0.62*	0.60 - 0.64	0.59*	0.58 - 0.60	0.71*	0.68 - 0.74	0.61*	0.56 - 0.67	0.86*	0.77 - 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 - 1.31	0.86*	0.83 - 0.89	1.32*	1.30 - 1.34	0.93*	0.89 - 0.97	0.98	0.93 - 1.04	1.40*	1.29 - 1.51
65+	1.87*	1.83 - 1.90	1.23*	1.19 - 1.28	1.78*	1.74 - 1.82	1.23*	1.18 - 1.29	1.78*	1.69 - 1.88	1.92*	1.80 - 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 - 0.75	1.49*	1.45 - 1.53	0.74*	0.73 - 0.76	1.51*	1.47 - 1.55	0.78*	0.73 - 0.82	1.60*	1.45 - 1.76
Boomtown	1.07*	1.05 - 1.08	1.78*	1.73 - 1.83	1.07*	1.05 - 1.09	1.81*	1.76 - 1.86	0.99	0.93 - 1.06	1.89*	1.70 - 2.09
General township	1.67*	1.64 - 1.70	2.31*	2.25 - 2.38	1.67*	1.64 - 1.70	2.37*	2.30 - 2.44	1.50*	1.41 - 1.59	2.42*	2.18 - 2.68
Rural area	2.36*	2.31 - 2.41	2.74*	2.66 - 2.83	2.38*	2.33 - 2.43	2.77*	2.68 - 2.87	1.88*	1.75 - 2.02	2.94*	2.63 - 3.29
Motorcycle engine capacity												
≥51cc	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
≤50cc					1.25*	1.23 - 1.27	1.18*	1.15 - 1.20				

	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
Drunk driving												
No (BAC[a] ≤0.03%)	1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)	
Yes (BAC[a]>0.03%)	3.75*	3.67 - 3.83	2.80*	2.73 - 2.87	3.91*	3.83 - 4.00	2.64*	2.58 - 2.71	1.69*	1.43 - 2.00	1.47*	1.23 - 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 - 2.14	1.77*	1.74 - 1.81	2.27*	2.22 - 2.31	1.73*	1.69 - 1.77	1.40*	1.26 - 1.55	1.24*	1.12 - 1.38
License												
Yes	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
No					2.05*	2.01 - 2.09	1.36*	1.33 - 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 - 1.47	1.01	0.98 - 1.05	1.44*	1.39 - 1.49	1.00	0.96 - 1.03	1.21*	1.07 - 1.36	1.16*	1.03 - 1.32
Crossroads/Roundabout	0.71*	0.70 - 0.72	0.90*	0.88 - 0.92	0.71*	0.70 - 0.72	0.90*	0.88 - 0.92	0.84*	0.80 - 0.89	0.94	0.87 - 1.00
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 - 1.83	1.08*	1.03 - 1.12	1.75*	1.68 - 1.82	1.05*	1.00 - 1.09	1.56*	1.38 - 1.76	1.28*	1.13 - 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 - 1.57	0.98	0.94 - 1.01	1.53*	1.49 - 1.57	0.97	0.93 - 1.00	1.59*	1.47 - 1.73	1.06	0.94 - 1.20
Others (Township road/Private road)	0.59*	0.58 - 0.60	0.83*	0.81 - 0.85	0.59*	0.58 - 0.61	0.82*	0.80 - 0.85	0.60*	0.57 - 0.65	0.85*	0.77 - 0.94
Road surface												

	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
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 - 0.85	0.85*	0.83 - 0.87	0.82*	0.80 - 0.84	0.84*	0.81 - 0.86	0.97	0.89 - 1.06	1.01	0.93 - 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 - 1.42	0.95	0.89 - 1.01	1.36*	1.28 - 1.44	0.96	0.90 - 1.03	1.16	0.87 - 1.56	1.00	0.74 - 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 - 1.16	0.99	0.95 - 1.03	1.14*	1.09 - 1.18	0.99	0.95 - 1.03	0.89	0.76 - 1.05	0.92	0.78 - 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 - 1.33	1.02	1.00 - 1.04	1.31*	1.29 - 1.33	1.03*	1.01 - 1.05	1.10*	1.04 - 1.17	0.93	0.87 - 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 - 0.93	1.21*	1.19 - 1.24	0.92*	0.91 - 0.94	1.21*	1.19 - 1.23	0.91*	0.86 - 0.96	1.09*	1.02 - 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 - 0.83	0.74*	0.73 - 0.76	0.82*	0.80 - 0.83	0.74*	0.73 - 0.76	0.84*	0.80 - 0.89	0.80*	0.75 - 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 - 2.38	1.75*	1.71 - 1.79	2.42*	2.38 - 2.47	1.76*	1.72 - 1.79	1.68*	1.50 - 1.88	1.56*	1.38 - 1.76

[a]BAC: Blood alcohol concentration

The pooled model revealed that bicyclists were 18% significantly less likely to be hospitalised for head injuries than motorcyclists were (AOR=0.82; CI=0.79-0.85). Moreover, factors such as the female (AOR=1.08, CI=1.07-1.10), age 65 or above (AOR=1.23, CI=1.19-1.28), rural areas (AOR=2.74, CI=2.66-2.83), BAC level>0.03% (AOR=2.80, CI=2.73-2.87), no use of a helmet (AOR=1.77, CI=1.74-1.81), darkness (AOR=1.08, CI=1.03-1.12), no separator of divided traffic direction (AOR=1.21, CI=1.19-1.24), and single-vehicle crash (AOR=1.75, CI=1.71-1.79) were found to be the 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 motorcyclists and bicyclists for head injuries were similar to those of the pooled model. Noteworthy results include that female motorcyclists (AOR=1.03) and elderly motorcyclists and bicyclists (AORs=1.23 and 1.92, 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 motorcyclists and bicyclists (AORs=2.77 and 2.94, respectively). The odds of hospitalisation were higher in riders of mopeds who sustained head injuries than in heavy-motorcycles riders (AOR=1.18). Intoxicated motorcyclists and bicyclists had a higher risk of hospitalisation for head injuries (AORs=1.48 and 2.64, respectively). Riding without helmets was found to be a risk factor in both motorcyclists and bicyclists (AORs=1.73 and 1.24, 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 risks of hospitalisation for head injuries among bicyclists (AORs=1.16 and 1.28, respectively).

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

Discussions

To ascertain 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 populations. 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 motorcyclists and bicyclists in Taiwan. The conclusions drawn from the current research can therefore be more reliable than other studies that solely used a single dataset.

The current research is limited by the fact that death data are not explicitly recorded in the NHIRD. Patients would die even if they are hospitalised. Unfortunately no such data is available from the NHIRD – these patients are recorded as "hospitalisation" instead of "deaths". Future research may attempt to obtain death data that are unavailable from the NHIRD, which would open up 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 the adjustment of this result for other factors in the multivariate analysis, bicyclists have lower risks of hospitalisation. The results here 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 purpose and 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 motorcyclists and bicyclists were estimated. The results revealed that contributory factors to hospitalisation for head injuries are similar among motorcyclists and bicyclists. For instance, dusk or dawn was associated with a higher risk of hospitalisation for head injuries among motorcyclists and bicyclists. The result here adds to existing literature of motorcycle and bicycle road safety by concluding that diminished light conditions are associated not only with accident occurrence [25 26] but also with head injury-related hospitalisation. It seems clear here that enhancing conspicuity, in particular in diminished light conditions, may be an effective countermeasure to reduce both accident risk and its consequences.

Our regression models revealed that the risk of hospitalisation is higher among elderly motorcyclists and bicyclists who sustained head injuries. Such a finding is in agreement with that of Ekman et al. (2001)[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 motorcyclists and bicyclists involved in single-vehicle crashes. This finding may be attributable to higher crash velocities being common in single-vehicle 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 (e.g., electric bicycles that now in general may travel at more than 25 km/h[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 that concluded that compared with riders in cities, riders in rural areas were 7 times less likely to wear helmets. In addition, a national survey administrated by the HPA[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 revealed that the risk of hospitalisation was higher in both motorcyclists and bicyclists 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.

Unanswered questions remained in the current research include what other factors may affect hospitalisation due to head injuries among motorcyclists and cyclists. Future research may attempt to obtain these 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 electronic device use (e.g., phone and MP3 players) that have been increasingly used when riding.

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Pai CW contributes to data analysis, interpretation of the data, and final approval of the version to be published.

Chen YC contributes to data analysis, and final approval of the version to be published.

Lin HY contributes to the design of the work, data analysis, interpretation of the data, drafting the manuscript and final approval of the version to be published.

Chen PL contributes to the design of the work, data analysis, interpretation of the data,

drafting the manuscript and final approval of the version to be published.

The authors declare to have no conflict of interests.

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The National Traffic Accident Dataset and the National Health Insurance Research Database (NHIRD), which are open to the researchers in Taiwan, are available from the Health and Welfare Data Science Center (http://dep.mohw.gov.tw/DOS/np-2497-113.html). Only citizens of Taiwan who fulfill the requirements of conducting research projects are eligible to apply for the NHIRD and National Traffic Accident Dataset. The use of NHIRD and National Traffic Accident Dataset are limited to research purposes only. Applicants must follow the Computer-Processed Personal Data Protection Law.

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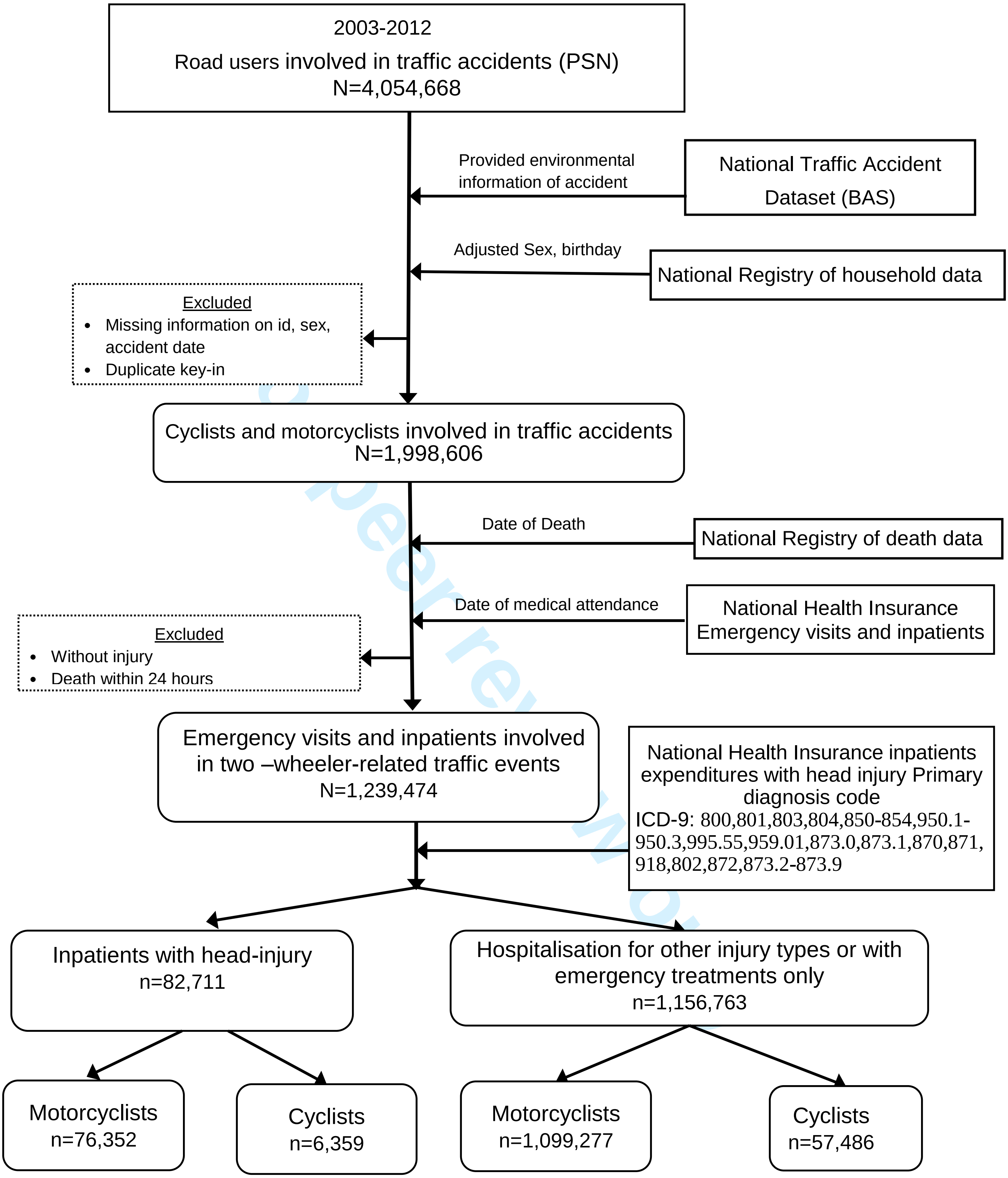
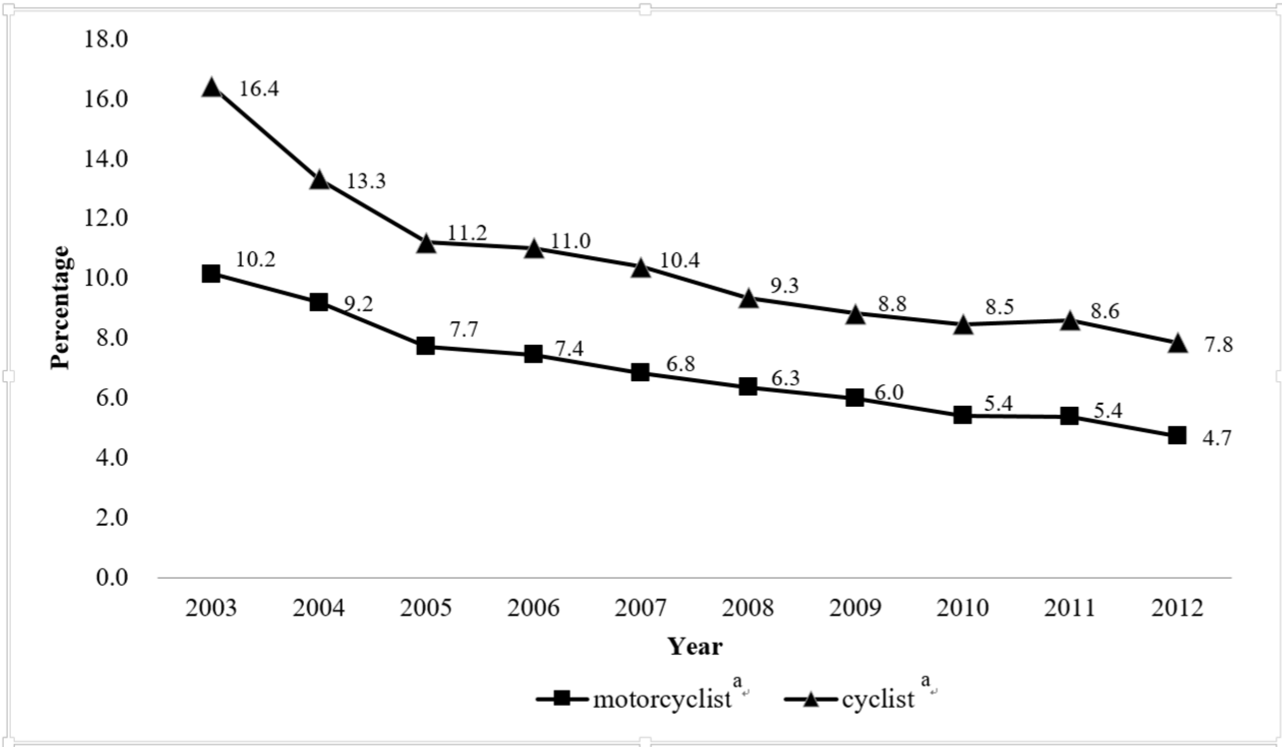


Appendix 1. Study flow diagram



Appendix 2. Trend of head injuries among two-wheeler riders involved in all emergency and inpatient visits for two-wheeler traffic accidents.

[a] :significantly decreasing according to the Mann-Kendall trend test

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-8
Objectives	3	State specific objectives, including any prespecified hypotheses	8
Methods			
Study design	4	Present key elements of study design early in the paper	9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	9-11
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	10-11
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	11-12
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9-12
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	10-11
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	10-11
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking	10-11

account of sampling strategy	
(*e*) Describe any sensitivity analyses	N/A

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8-9
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	Appendix 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	8
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	*8-9, 11*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	19-24
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	24-25
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	27
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	25-27
Generalisability	21	Discuss the generalisability (external validity) of the study results	N/A
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	28

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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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 was the head, and bicyclists were 2.6 times more likely to be fatally injured than motorcyclists were. 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, compared with motorcyclists, have higher odds of head-related hospitalisation. This study also aims to investigate the determinants of head-injury related hospitalisation among bicyclists and motorcyclists, respectively.

Methods

Using linked data of the National Traffic Accident Dataset and the National Health Insurance Research Database for the period between 2003 and 2012, this study investigates the crash characteristics of bicyclist and motorcyclist casualties presented 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 (e.g. human attributes, road and weather conditions, and vehicle characteristics) are related to hospital admission of those who sustained serious injuries.

Results

A total of 1239474 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 the 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 were (AOR=0.82; CI=0.79-0.85). Other important determinants of head-injury related hospitalisation for bicyclists and motorcyclists include female riders, elderly riders, crashes that occurred 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.

Keywords: Bicyclist and motorcyclist; Head injury; Hospitalisation; Crashes

Strengths and limitations of this study

- This is a comprehensive study using the linked data from these two datasets which cover 99.9% of populations.
- Our results derived from the linked datasets can be more reliable than those using a single database alone.
- Hospitalisation data can be more clinically reliable than injury-severity data that are commonly adopted in past studies.
- The study is limited by the data that are unavailable from the two datasets such as electronic device use (e.g., 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 were 2.6 times more likely to be fatally injured than motorcyclists were[4]. The head (approximately 61%) was the main body part that sustained injury resulting in death of these bicyclists[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. (2011) investigated motorcycle head injuries one 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 (the 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 bike sharing programmes have been implemented in several 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. (2003) 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], the United States[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 associate of helmet use with 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. (2001)[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].

When reviewed together, literature has suggested 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 occurs when a vehicle collides with other road users, or other stationary objects such as a tree, telegraphy, or traffic island), compared with motorcyclists, are more likely to be hospitalised due to head injuries. The primary aim of this study was to determine whether bicyclist casualties, compared with motorcyclists, have higher odds of head-related hospitalisation. Another important research 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 etc. This study also aims to investigate the determinants of head-injury related hospitalisation among bicyclists and motorcyclists, respectively.

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 Center, 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 National Traffic Accident Dataset can be found in the study of Chen et al. (2016)[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 resident of Taiwan. The NHIRD comprises the 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

140 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).

148 ICD-9-CM N-codes 800 to 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 Center, Taiwan. No individual patient or casualty can be identified and therefore, our study was exempted from review by an institutional review board (IRB #:201409033).

157 The flow chart of sample selection from the National Traffic Accident Dataset and the NHIRD is presented in supplementary appendix 1. The current research

examined data for the period between 2003 and 2012. By linking the National Traffic Accident Dataset and the NHIRD, a total of 4054668 casualties involved in MVCs were identified. Among the 4054668 casualties, 1998606 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 1239474 casualties were either hospitalised or admitted to emergency departments. Among these 1239474 casualties, 82711 were hospitalised for head injuries (treated as cases), and 1156763 were hospitalised for other injury types or received emergency treatment only (treated as controls).

Variable definitions

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. Demographic data were collected for the casualties, namely gender (male and female); age (four groups: <18, 18-40, 41-64, and 65 or above); blood alcohol consumption (BAC) level (<=0.03% or >0.03%); license status (yes: with a 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 the engine size (<=50cc and >=51cc or above) Road and environment factors were the following variables: path type (straight road, curved road, or crossroads/ roundabout), lighting (daylight, dusk/ dawn); road type (provincial highway, county road, or others); road surface (dry, or 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 which was divided into fixed objects and unfixed objects.

Statistical analysis

Trend of head-related injuries among two-wheeler riders due to MVCs is compared and the difference in hospitalisation percentages is tested with the Mann-Kendall trend test. Distribution of head-injury related hospitalisation and non head-injury related hospitalisation by a set of variables (e.g., human attributes, environmental factors, and vehicle characteristics) is reported. Chi-square tests are conducted for comparing hospitalised patients (for head-related injuries) with hospitalised ones (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, the variables that have significance level ($p<0.2$) in the univariate logistic regression models were then incorporated into the multivariate logistic regression models. VIF (variance inflation factor) was conducted 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 contributory factors that may be different across bicyclist and motorcyclist casualties.

Results

We further illustrate the trend of head injuries sustained by bicyclists and motorcyclists who presented to the emergency rooms or were admitted to hospitals (see 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 principal diagnoses of injuries to various body regions resulting in the 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. Furthermore, 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 to sustain a TBI was higher than that of motorcyclists (41.4% vs. 29.3%).

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

Total			Motorcyclists			Bicyclists		
N-code	N	%	N-code	N	%	N-code	N	%
Traumatic brain injury	67464	30.0	Traumatic brain injury	61826	29.3	Traumatic brain injury	5638	41.4
Lower leg and ankle fracture	27358	12.2	Lower leg and ankle fracture	25908	12.3	Lower leg and ankle fracture	1450	10.7
Shoulder and upper arm fracture	20712	9.2	Shoulder and upper arm fracture	19839	9.4	Forearm and elbow fracture	939	6.9
Forearm and elbow fracture	16782	7.5	Forearm and elbow fracture	15843	7.5	Shoulder and upper arm fracture	873	6.4
Other head, face, and neck	15247	6.8	Other head, face, and neck	14526	6.9	Hip fracture	743	5.5
Upper leg and thigh fracture	10975	4.9	Upper leg and thigh fracture	10528	5.0	Other head, face, and neck	721	5.3
Sternum/ribs/pelvis fracture	10888	4.8	Sternum/ribs/pelvis fracture	10509	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	32592	14.5	Other injuries	30416	14.4	Other injuries	1317	9.7

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 includes that the proportion of bicyclists hospitalised for head injuries was higher than that of motorcyclists (10.0% vs. 6.5%). As reported in Table 2, there are interesting data on helmet use among injured bicyclists and motorcyclists, confirming what was stated in introduction: compared to the injured motorcyclists that had much higher helmet-use rate (91.57%), the injured bicyclists were less likely to wear helmet (8.93%) since there is no law requiring helmet use for bicyclists. Other noteworthy results from Tables 2-4 are not interpreted here for brevity.

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*	n	%	n	%	*p*	n	%	n	%	*p*
Total	82711	6.7	1156763	93.3		76352	6.5	1099277	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 urbanized 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 urbanized 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															
≥51cc	60411	6.2	907379	93.8	<0.001	60411	6.2	907379	93.8	<0.001	NA	NA	NA	NA	NA
≤50cc	15941	7.7	191898	92.3		15941	7.7	191898	92.3		NA	NA	NA	NA	
Drunk Driving															
No (BAC[a] ≤0.03%)	71070	6.0	1108293	94.0	<0.001	64876	5.8	1051700	94.2	<0.001	6194	9.9	56593	90.1	<0.001
Yes (BAC[a]>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	1011701	94.1	<0.001	63158	5.9	1006568	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	

[a]BAC: Blood alcohol concentration

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*	n	%	n	%	*p*	n	%	n	%	*p*
Path Type															
Straight road	34581	7.9	404337	92.1	<0.001	31629	7.7	379675	92.3	<0.001	2952	10.7	24662	89.3	<0.001
Curved road	4344	9.1	43312	90.9		4031	9.0	40950	91.0		313	11.7	2362	88.3	
Crossroads/Roundabout	43786	5.8	709114	94.2		40692	5.7	678652	94.3		3094	9.2	30462	90.8	
Lighting															
Daylight	79618	6.6	1131762	93.4	<0.001	73593	6.4	1076250	93.6	<0.001	6025	9.8	55512	90.2	<0.001
Dusk or dawn	3093	11.0	25001	89.0		2759	10.7	23027	89.3		334	14.5	1974	85.5	
Road type															
Provincial Highway	7368	10.5	62628	89.5	<0.001	6833	10.3	59461	89.7	<0.001	535	14.5	3167	85.5	<0.001
County road	8923	9.6	84422	90.4		8185	9.3	80043	90.7		738	14.4	4379	85.6	
Others(Township road/ Private road)	66404	6.2	1009614	93.8		61318	6.0	959677	94.0		5086	9.2	49937	90.8	
Road surface															
Dry	74774	6.8	1024947	93.2	<0.001	69030	6.6	973197	93.4	<0.001	5744	10.0	51750	90.0	0.482
Wet/Slippery	7937	5.7	131816	94.3		7322	5.5	126080	94.5		615	9.7	5736	90.3	
Road defect															
No	81560	6.7	1144635	93.3	<0.001	75251	6.5	1087538	93.5	<0.001	6309	10.0	57097	90.0	0.367
Yes	1151	8.7	12128	91.3		1101	8.6	11739	91.4		50	11.4	389	88.6	
Barrier															
No	79862	6.7	1120926	93.3	<0.001	73658	6.5	1065006	93.5	<0.001	6204	10.0	55920	90.0	0.224
Yes	2849	7.4	35837	92.6		2694	7.3	34271	92.7		155	9.0	1566	91.0	

Traffic signal															
Yes	25993	5.7	434048	94.3	<0.001	24265	5.5	417304	94.5	<0.001	1728	9.4	16744	90.6	0.003
No	56718	7.3	722715	92.7		52087	7.1	681973	92.9		4631	10.2	40742	89.8	
Separation of traffic directions															
Yes	48122	6.9	648417	93.1	<0.001	44113	6.7	613461	93.3	<0.001	4009	10.3	34956	89.7	0.002
No	34589	6.4	508346	93.6		32239	6.2	485816	93.8		2350	9.4	22530	90.6	
Traffic island															
Yes	25552	7.6	309424	92.4	<0.001	23531	7.4	293206	92.6	<0.001	2021	11.1	16218	88.9	<0.001
No	57159	6.3	847339	93.7		52821	6.1	806071	93.9		4338	9.5	41268	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*	n	%	n	%	*p*	n	%	n	%	*p*
Crash type															
Multiple vehicle	66457	6.0	1047128	94.0	<0.001	60466	5.7	991673	94.3	<0.001	5991	9.8	5981.2	90.2	<0.001
Single vehicle	16245	12.9	109635	87.1		15877	12.9	107604	87.1		368	15.3	352.7	84.7	
Object type															
Unfixed objects	10829	11.3	84984	88.7	<0.001	10542	11.2	83360	88.8	<0.001	287	15	272	85.0	0.461
Fixed objects	5416	18.0	24651	82.0		5335	18.0	24244	82.0		81	16.6	64.4	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	40.7	84.7	0.282
Traffic islands/Trees/Poles/Others	3842	20.1	15270	79.9		3817	20.1	15172	79.9		25	20.3	4.7	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	7.1	95.1	<0.001
Skidding vehicle	8587	13.4	55615	86.6		8312	13.3	54226	86.7		275	16.5	258.5	83.5	

Table 5 lists the crude and adjusted odds ratios (ORs) 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 variance inflation factor being <3, there was no need to be concerned about multi-collinearity in the models.

Table 5. Crude and adjusted odds ratios of hospitalization for head injury in two-wheeled vehicle crashed accidents

	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 - 1.64	0.82*	0.79 - 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 - 0.88	1.08*	1.07 - 1.10	0.86*	0.84 - 0.87	1.03*	1.02 - 1.05	0.98	0.93 - 1.03	1.01	0.95 - 1.06
Age(year)												
<18	0.57*	0.57 - 0.58	0.62*	0.60 - 0.64	0.59*	0.58 - 0.60	0.71*	0.68 - 0.74	0.61*	0.56 - 0.67	0.86*	0.77 - 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 - 1.31	0.86*	0.83 - 0.89	1.32*	1.30 - 1.34	0.93*	0.89 - 0.97	0.98	0.93 - 1.04	1.40*	1.29 - 1.51
65+	1.87*	1.83 - 1.90	1.23*	1.19 - 1.28	1.78*	1.74 - 1.82	1.23*	1.18 - 1.29	1.78*	1.69 - 1.88	1.92*	1.80 - 2.06
Location												
Highly urbanized area	1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)	
Medium urbanized area	0.74*	0.73 - 0.75	1.49*	1.45 - 1.53	0.74*	0.73 - 0.76	1.51*	1.47 - 1.55	0.78*	0.73 - 0.82	1.60*	1.45 - 1.76
Boomtown	1.07*	1.05 - 1.08	1.78*	1.73 - 1.83	1.07*	1.05 - 1.09	1.81*	1.76 - 1.86	0.99	0.93 - 1.06	1.89*	1.70 - 2.09
General township	1.67*	1.64 - 1.70	2.31*	2.25 - 2.38	1.67*	1.64 - 1.70	2.37*	2.30 - 2.44	1.50*	1.41 - 1.59	2.42*	2.18 - 2.68
Rural area	2.36*	2.31 - 2.41	2.74*	2.66 - 2.83	2.38*	2.33 - 2.43	2.77*	2.68 - 2.87	1.88*	1.75 - 2.02	2.94*	2.63 - 3.29
Motorcycle engine capacity												
≥51cc	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
≤50cc					1.25*	1.23 - 1.27	1.18*	1.15 - 1.20				

	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
Drunk driving												
No (BAC[a] ≤0.03%)	1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)	
Yes (BAC[a]>0.03%)	3.75*	3.67 - 3.83	2.80*	2.73 - 2.87	3.91*	3.83 - 4.00	2.64*	2.58 - 2.71	1.69*	1.43 - 2.00	1.47*	1.23 - 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 - 2.14	1.77*	1.74 - 1.81	2.27*	2.22 - 2.31	1.73*	1.69 - 1.77	1.40 *	1.26 - 1.55	1.24*	1.12 - 1.38
License												
Yes	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
No					2.05*	2.01 - 2.09	1.36*	1.33 - 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 - 1.47	1.01	0.98 - 1.05	1.44*	1.39 - 1.49	1.00	0.96 - 1.03	1.21*	1.07 - 1.36	1.16*	1.03 - 1.32
Crossroads/Roundabout	0.71*	0.70 - 0.72	0.90*	0.88 - 0.92	0.71*	0.70 - 0.72	0.90*	0.88 - 0.92	0.84*	0.80 - 0.89	0.94	0.87 - 1.00
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 - 1.83	1.08*	1.03 - 1.12	1.75*	1.68 - 1.82	1.05*	1.00 - 1.09	1.56*	1.38 - 1.76	1.28*	1.13 - 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 - 1.57	0.98	0.94 - 1.01	1.53*	1.49 - 1.57	0.97	0.93 - 1.00	1.59*	1.47 - 1.73	1.06	0.94 - 1.20
Others (Township road/Private road)	0.59*	0.58 - 0.60	0.83*	0.81 - 0.85	0.59*	0.58 - 0.61	0.82*	0.80 - 0.85	0.60*	0.57 - 0.65	0.85*	0.77 - 0.94
Road surface												

	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
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 - 0.85	0.85*	0.83 - 0.87	0.82*	0.80 - 0.84	0.84*	0.81 - 0.86	0.97	0.89 - 1.06	1.01	0.93 - 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 - 1.42	0.95	0.89 - 1.01	1.36*	1.28 - 1.44	0.96	0.90 - 1.03	1.16	0.87 - 1.56	1.00	0.74 - 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 - 1.16	0.99	0.95 - 1.03	1.14*	1.09 - 1.18	0.99	0.95 - 1.03	0.89	0.76 - 1.05	0.92	0.78 - 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 - 1.33	1.02	1.00 - 1.04	1.31*	1.29 - 1.33	1.03*	1.01 - 1.05	1.10*	1.04 - 1.17	0.93	0.87 - 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 - 0.93	1.21*	1.19 - 1.24	0.92*	0.91 - 0.94	1.21*	1.19 - 1.23	0.91*	0.86 - 0.96	1.09*	1.02 - 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 - 0.83	0.74*	0.73 - 0.76	0.82*	0.80 - 0.83	0.74*	0.73 - 0.76	0.84*	0.80 - 0.89	0.80*	0.75 - 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 - 2.38	1.75*	1.71 - 1.79	2.42*	2.38 - 2.47	1.76*	1.72 - 1.79	1.68*	1.50 - 1.88	1.56*	1.38 - 1.76

[a]BAC: Blood alcohol concentration

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

Discussions

To ascertain 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 populations. 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 can therefore be 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 while 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 head-injury related hospitalisation not only for bicyclists but also for motorcyclists.

The current research is limited by the fact that death data are not explicitly recorded in the NHIRD. Patients would die even if they are hospitalised. Unfortunately no such data is available from the NHIRD – these patients are recorded as "hospitalisation" instead of "deaths". Future research may attempt to obtain death data that are unavailable from the NHIRD, which would open up 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 the adjustment of this result for other factors in the multivariate analysis, bicyclists have lower risks of hospitalisation. The results here 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 purpose and 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 bicyclists and motorcyclists. The result here adds to existing literature of motorcycle and bicycle road safety by concluding that diminished light conditions are associated not only with accident occurrence [25 26] but also with head injury-related hospitalisation. It seems clear here that enhancing conspicuity, in particular in diminished light conditions, may be an effective countermeasure to reduce both

accident risk 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. (2001)[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 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 (e.g., electric bicycles that now in general may travel at more than 25 km/h[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

334 conjecture is supported by the findings of past studies[35] on motorcycle helmet use that
335 concluded that compared with riders in cities, riders in rural areas were 7 times less likely to
336 wear helmets. In addition, a national survey administrated by the HPA[24] reported that the
337 bicycle helmet use rate in urbanised areas was 1.5 times higher than that in rural areas.
338 Moreover, the requirement of additional time for emergency-vehicle response in rural areas
339 and the lower availability of medical resources in such areas[36] predispose people with head
340 injuries to hospitalisation.

341 The study results revealed that the risk of hospitalisation was higher in both bicyclists and
342 motorcyclists who sustained injuries in MVCs on roadways where traffic directions were not
343 separated. This may be because of higher crash velocities at such locations. The road sections
344 may be wide, and speed limits may be higher for locations where the traffic is not divided by
345 any traffic barrier. Therefore, head injuries resulting from accidents in these locations may
346 require hospitalisation.

347 Unanswered questions remained in the current research include what other factors may
348 affect hospitalisation due to head injuries among bicyclists and motorcyclists. Future research
349 may attempt to obtain these variables that are not available from the National Traffic Accident
350 Dataset and the NHIRD. These factors include motorcycle and bicycle types (a greater
351 classification of engine size and electric bicycles), traffic volume, geometric characteristics,
352 and electronic device use (e.g., phone and MP3 players) that have been increasingly used

when riding.

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Chen YC contributes to data analysis, and final approval of the version to be published.

Lin HY contributes to the design of the work, data analysis, interpretation of the data, drafting the manuscript and final approval of the version to be published.

Chen PL contributes to the design of the work, data analysis, interpretation of the data, drafting the manuscript and final approval of the version to be published.

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The National Traffic Accident Dataset and the National Health Insurance Research Database (NHIRD), which are open to the researchers in Taiwan, are available from the Health and

Welfare Data Science Center (http://dep.mohw.gov.tw/DOS/np-2497-113.html). Only citizens of Taiwan who fulfil the requirements of conducting research projects are eligible to apply for the NHIRD and National Traffic Accident Dataset. The use of NHIRD and National Traffic Accident Dataset are limited to research purposes only. Applicants must follow the Computer-Processed Personal Data Protection Law.

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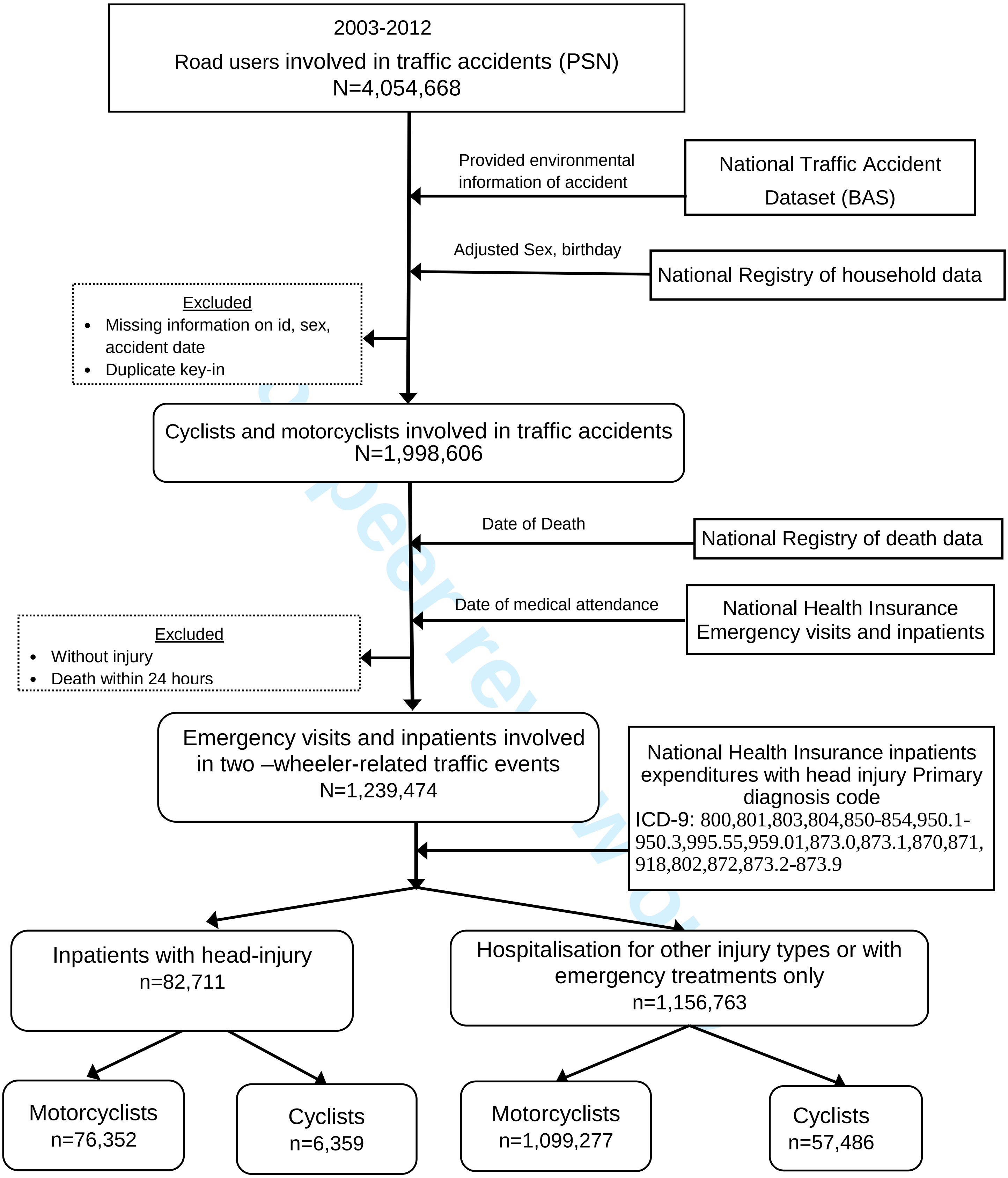
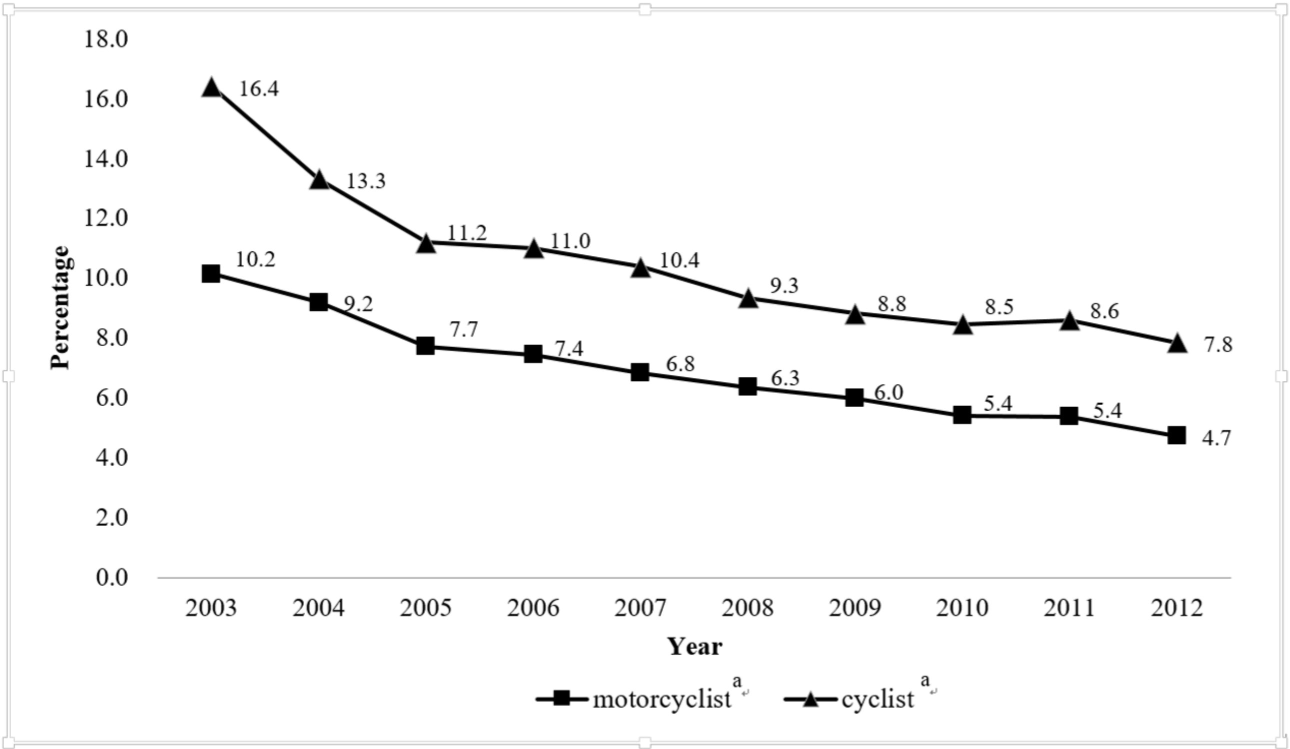


Appendix 1. Study flow diagram



Appendix 2. Trend of head injuries among two-wheeler riders involved in all emergency and inpatient visits for two-wheeler traffic accidents.

[a] :significantly decreasing according to the Mann-Kendall trend test

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-8
Objectives	3	State specific objectives, including any prespecified hypotheses	8
Methods			
Study design	4	Present key elements of study design early in the paper	9
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	9-11
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	10-11
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	11-12
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	9-12
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	10-11
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	12
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	10-11
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking	10-11

account of sampling strategy		
(*e*) Describe any sensitivity analyses	N/A	

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8-9
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	Appendix 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	8
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	*8-9, 11*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	19-24
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	24-25
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	27
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	25-27
Generalisability	21	Discuss the generalisability (external validity) of the study results	N/A
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	28

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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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 was the head, and bicyclists were 2.6 times more likely to be fatally injured than motorcyclists were. 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, compared with motorcyclists, have higher odds of head-related hospitalisation. This study also aims to investigate the determinants of head-injury related hospitalisation among bicyclists and motorcyclists, respectively.

Methods

Using linked data of the National Traffic Accident Dataset and the National Health Insurance Research Database for the period between 2003 and 2012, this study investigates the crash characteristics of bicyclist and motorcyclist casualties presented 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 (e.g. human attributes, road and weather conditions, and vehicle characteristics) are related to hospital admission of those who sustained serious injuries.

Results

A total of 1239474 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 the 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 were (AOR=0.82; CI=0.79-0.85). Other important determinants of head-injury related hospitalisation for bicyclists and motorcyclists include female riders, elderly riders, crashes that occurred 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.

Keywords: Bicyclist and motorcyclist; Head injury; Hospitalisation; Crashes

Strengths and limitations of this study

- ■ This is a comprehensive study using the linked data from these two datasets which cover 99.9% of populations.
- ■ Our results derived from the linked datasets can be more reliable than those using a single database alone.
- ■ Hospitalisation data can be more clinically reliable than injury-severity data that are commonly adopted in past studies.
- ● The study is limited by the data that are unavailable from the two datasets such as electronic device use (e.g., 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 were 2.6 times more likely to be fatally injured than motorcyclists were[4]. The head (approximately 61%) was the main body part that sustained injury resulting in death of these bicyclists[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. (2011) investigated motorcycle head injuries one 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 (the 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 bike sharing programmes have been implemented in several 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. (2003) 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], the United States[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 associate of helmet use with 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. (2001)[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].

When reviewed together, literature has suggested 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 occurs when a vehicle collides with other road users, or other stationary objects such as a tree, telegraphy, or traffic island), compared with motorcyclists, are more likely to be hospitalised due to head injuries. The primary aim of this study was to determine whether bicyclist casualties, compared with motorcyclists, have higher odds of head-related hospitalisation. Another important research 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 etc. This study also aims to investigate the determinants of head-injury related hospitalisation among bicyclists and motorcyclists, respectively.

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 Center, 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 National Traffic Accident Dataset can be found in the study of Chen et al. (2016)[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 resident of Taiwan. The NHIRD comprises the 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 to 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 Center, Taiwan. No individual patient or casualty can be identified and 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 supplementary appendix 1. The current research examined data for the period between 2003 and 2012. By linking the National Traffic Accident Dataset and the NHIRD, a total of 4054668 casualties involved in MVCs were identified. Among the 4054668 casualties, 1998606 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 1239474 casualties were either hospitalised or admitted to emergency departments. Among these 1239474 casualties, 82711 were hospitalised for head injuries (treated as cases), and 1156763 were hospitalised for other injury types or received emergency treatment only (treated as controls).

Variable definitions

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. Demographic data were collected for the casualties, namely gender (male and female); age (four groups: <18, 18-40, 41-64, and 65 or above); blood alcohol consumption (BAC) level (<=0.03% or >0.03%); license status (yes: with a 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 the engine size (<=50cc and >=51cc or above) Road and environment factors were the following variables: path type (straight road, curved road, or crossroads/ roundabout), lighting (daylight, dusk/ dawn); road type (provincial highway, county road, or others); road surface (dry, or 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 which was divided into fixed objects and unfixed objects.

Statistical analysis

Trend of head-related injuries among two-wheeler riders due to MVCs is compared and the difference in hospitalisation percentages is tested with the Mann-Kendall trend test. Distribution of head-injury related hospitalisation and non head-injury related hospitalisation by a set of variables (e.g., human attributes, environmental factors, and vehicle characteristics) is reported. Chi-square tests are conducted for comparing hospitalised patients (for head-related injuries) with hospitalised ones (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, the variables that have significance level ($p<0.2$) in the univariate logistic regression models were then incorporated into the multivariate logistic regression models. VIF (variance inflation factor) was conducted 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 contributory factors that may be different across bicyclist and motorcyclist casualties.

Results

We further illustrate the trend of head injuries sustained by bicyclists and motorcyclists who presented to the emergency rooms or were admitted to hospitals (see 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 principal diagnoses of injuries to various body regions resulting in the 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. Furthermore, 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 to sustain a TBI was higher than that of motorcyclists (41.4% vs. 29.3%).

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

Total			Motorcyclists			Bicyclists		
N-code	N	%	N-code	N	%	N-code	N	%
Traumatic brain injury	67464	30.0	Traumatic brain injury	61826	29.3	Traumatic brain injury	5638	41.4
Lower leg and ankle fracture	27358	12.2	Lower leg and ankle fracture	25908	12.3	Lower leg and ankle fracture	1450	10.7
Shoulder and upper arm fracture	20712	9.2	Shoulder and upper arm fracture	19839	9.4	Forearm and elbow fracture	939	6.9
Forearm and elbow fracture	16782	7.5	Forearm and elbow fracture	15843	7.5	Shoulder and upper arm fracture	873	6.4
Other head, face, and neck	15247	6.8	Other head, face, and neck	14526	6.9	Hip fracture	743	5.5
Upper leg and thigh fracture	10975	4.9	Upper leg and thigh fracture	10528	5.0	Other head, face, and neck	721	5.3
Sternum/ribs/pelvis fracture	10888	4.8	Sternum/ribs/pelvis fracture	10509	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	32592	14.5	Other injuries	30416	14.4	Other injuries	1317	9.7

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 includes that the proportion of bicyclists hospitalised for head injuries was higher than that of motorcyclists (10.0% vs. 6.5%). As reported in Table 2, there are interesting data on helmet use among injured bicyclists and motorcyclists, confirming what was stated in introduction: compared to the injured motorcyclists that had much higher helmet-use rate (91.57%), the injured bicyclists were less likely to wear helmet (8.93%) since there is no law requiring helmet use for bicyclists. Other noteworthy results from Tables 2-4 are not interpreted here for brevity.

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*	n	%	n	%	*p*	n	%	n	%	*p*
Total	82711	6.7	1156763	93.3		76352	6.5	1099277	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 urbanized 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 urbanized 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															
≥51cc	60411	6.2	907379	93.8	<0.001	60411	6.2	907379	93.8	<0.001	NA	NA	NA	NA	NA
≤50cc	15941	7.7	191898	92.3		15941	7.7	191898	92.3		NA	NA	NA	NA	
Drunk Driving															
No (BAC[a] ≤0.03%)	71070	6.0	1108293	94.0	<0.001	64876	5.8	1051700	94.2	<0.001	6194	9.9	56593	90.1	<0.001
Yes (BAC[a]>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	1011701	94.1	<0.001	63158	5.9	1006568	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	

[a]BAC: Blood alcohol concentration

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*	n	%	n	%	*p*	n	%	n	%	*p*
Path Type															
Straight road	34581	7.9	404337	92.1	<0.001	31629	7.7	379675	92.3	<0.001	2952	10.7	24662	89.3	<0.001
Curved road	4344	9.1	43312	90.9		4031	9.0	40950	91.0		313	11.7	2362	88.3	
Crossroads/Roundabout	43786	5.8	709114	94.2		40692	5.7	678652	94.3		3094	9.2	30462	90.8	
Lighting															
Daylight	79618	6.6	1131762	93.4	<0.001	73593	6.4	1076250	93.6	<0.001	6025	9.8	55512	90.2	<0.001
Dusk or dawn	3093	11.0	25001	89.0		2759	10.7	23027	89.3		334	14.5	1974	85.5	
Road type															
Provincial Highway	7368	10.5	62628	89.5	<0.001	6833	10.3	59461	89.7	<0.001	535	14.5	3167	85.5	<0.001
County road	8923	9.6	84422	90.4		8185	9.3	80043	90.7		738	14.4	4379	85.6	
Others(Township road/ Private road)	66404	6.2	1009614	93.8		61318	6.0	959677	94.0		5086	9.2	49937	90.8	
Road surface															
Dry	74774	6.8	1024947	93.2	<0.001	69030	6.6	973197	93.4	<0.001	5744	10.0	51750	90.0	0.482
Wet/Slippery	7937	5.7	131816	94.3		7322	5.5	126080	94.5		615	9.7	5736	90.3	
Road defect															
No	81560	6.7	1144635	93.3	<0.001	75251	6.5	1087538	93.5	<0.001	6309	10.0	57097	90.0	0.367
Yes	1151	8.7	12128	91.3		1101	8.6	11739	91.4		50	11.4	389	88.6	
Barrier															
No	79862	6.7	1120926	93.3	<0.001	73658	6.5	1065006	93.5	<0.001	6204	10.0	55920	90.0	0.224
Yes	2849	7.4	35837	92.6		2694	7.3	34271	92.7		155	9.0	1566	91.0	

Traffic signal															
Yes	25993	5.7	434048	94.3	<0.001	24265	5.5	417304	94.5	<0.001	1728	9.4	16744	90.6	0.003
No	56718	7.3	722715	92.7		52087	7.1	681973	92.9		4631	10.2	40742	89.8	
Separation of traffic directions															
Yes	48122	6.9	648417	93.1	<0.001	44113	6.7	613461	93.3	<0.001	4009	10.3	34956	89.7	0.002
No	34589	6.4	508346	93.6		32239	6.2	485816	93.8		2350	9.4	22530	90.6	
Traffic island															
Yes	25552	7.6	309424	92.4	<0.001	23531	7.4	293206	92.6	<0.001	2021	11.1	16218	88.9	<0.001
No	57159	6.3	847339	93.7		52821	6.1	806071	93.9		4338	9.5	41268	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*	n	%	n	%	*p*	n	%	n	%	*p*
Crash type															
Multiple vehicle	66457	6.0	1047128	94.0	<0.001	60466	5.7	991673	94.3	<0.001	5991	9.8	5981.2	90.2	<0.001
Single vehicle	16245	12.9	109635	87.1		15877	12.9	107604	87.1		368	15.3	352.7	84.7	
Object type															
Unfixed objects	10829	11.3	84984	88.7	<0.001	10542	11.2	83360	88.8	<0.001	287	15	272	85.0	0.461
Fixed objects	5416	18.0	24651	82.0		5335	18.0	24244	82.0		81	16.6	64.4	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	40.7	84.7	0.282
Traffic islands/Trees/Poles/Others	3842	20.1	15270	79.9		3817	20.1	15172	79.9		25	20.3	4.7	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	7.1	95.1	<0.001
Skidding vehicle	8587	13.4	55615	86.6		8312	13.3	54226	86.7		275	16.5	258.5	83.5	

232

233 Table 5 lists the crude and adjusted odds ratios (ORs) of hospitalisation for head
234 injuries among bicyclists and motorcyclists using logistic regression models. Three
235 models were estimated: a pooled model that considered the variable “vehicle type” as
236 a risk factor and two separate models for bicyclists and motorcyclists. According to
237 the variance inflation factor being <3, there was no need to be concerned about
238 multi-collinearity in the models.

Table 5. Crude and adjusted odds ratios of hospitalization for head injury in two-wheeled vehicle crashed accidents

	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 - 1.64	0.82*	0.79 - 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 - 0.88	1.08*	1.07 - 1.10	0.86*	0.84 - 0.87	1.03*	1.02 - 1.05	0.98	0.93 - 1.03	1.01	0.95 - 1.06
Age(year)												
<18	0.57*	0.57 - 0.58	0.62*	0.60 - 0.64	0.59*	0.58 - 0.60	0.71*	0.68 - 0.74	0.61*	0.56 - 0.67	0.86*	0.77 - 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 - 1.31	0.86*	0.83 - 0.89	1.32*	1.30 - 1.34	0.93*	0.89 - 0.97	0.98	0.93 - 1.04	1.40*	1.29 - 1.51
65+	1.87*	1.83 - 1.90	1.23*	1.19 - 1.28	1.78*	1.74 - 1.82	1.23*	1.18 - 1.29	1.78*	1.69 - 1.88	1.92*	1.80 - 2.06
Location												
Highly urbanized area	1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)	
Medium urbanized area	0.74*	0.73 - 0.75	1.49*	1.45 - 1.53	0.74*	0.73 - 0.76	1.51*	1.47 - 1.55	0.78*	0.73 - 0.82	1.60*	1.45 - 1.76
Boomtown	1.07*	1.05 - 1.08	1.78*	1.73 - 1.83	1.07*	1.05 - 1.09	1.81*	1.76 - 1.86	0.99	0.93 - 1.06	1.89*	1.70 - 2.09
General township	1.67*	1.64 - 1.70	2.31*	2.25 - 2.38	1.67*	1.64 - 1.70	2.37*	2.30 - 2.44	1.50*	1.41 - 1.59	2.42*	2.18 - 2.68
Rural area	2.36*	2.31 - 2.41	2.74*	2.66 - 2.83	2.38*	2.33 - 2.43	2.77*	2.68 - 2.87	1.88*	1.75 - 2.02	2.94*	2.63 - 3.29
Motorcycle engine capacity												
≥51cc	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
≤50cc					1.25*	1.23 - 1.27	1.18*	1.15 - 1.20				

	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
Drunk driving												
No (BAC[a] ≤0.03%)	1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)		1.00 (ref.)	
Yes (BAC[a]>0.03%)	3.75*	3.67 - 3.83	2.80*	2.73 - 2.87	3.91*	3.83 - 4.00	2.64*	2.58 - 2.71	1.69*	1.43 - 2.00	1.47*	1.23 - 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 - 2.14	1.77*	1.74 - 1.81	2.27*	2.22 - 2.31	1.73*	1.69 - 1.77	1.40 *	1.26 - 1.55	1.24*	1.12 - 1.38
License												
Yes	---		---		1.00 (ref.)		1.00 (ref.)		---		---	
No					2.05*	2.01 - 2.09	1.36*	1.33 - 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 - 1.47	1.01	0.98 - 1.05	1.44*	1.39 - 1.49	1.00	0.96 - 1.03	1.21*	1.07 - 1.36	1.16*	1.03 - 1.32
Crossroads/Roundabout	0.71*	0.70 - 0.72	0.90*	0.88 - 0.92	0.71*	0.70 - 0.72	0.90*	0.88 - 0.92	0.84*	0.80 - 0.89	0.94	0.87 - 1.00
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 - 1.83	1.08*	1.03 - 1.12	1.75*	1.68 - 1.82	1.05*	1.00 - 1.09	1.56*	1.38 - 1.76	1.28*	1.13 - 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 - 1.57	0.98	0.94 - 1.01	1.53*	1.49 - 1.57	0.97	0.93 - 1.00	1.59*	1.47 - 1.73	1.06	0.94 - 1.20
Others (Township road/Private road)	0.59*	0.58 - 0.60	0.83*	0.81 - 0.85	0.59*	0.58 - 0.61	0.82*	0.80 - 0.85	0.60*	0.57 - 0.65	0.85*	0.77 - 0.94
Road surface												

	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
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 - 0.85	0.85*	0.83 - 0.87	0.82*	0.80 - 0.84	0.84*	0.81 - 0.86	0.97	0.89 - 1.06	1.01	0.93 - 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 - 1.42	0.95	0.89 - 1.01	1.36*	1.28 - 1.44	0.96	0.90 - 1.03	1.16	0.87 - 1.56	1.00	0.74 - 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 - 1.16	0.99	0.95 - 1.03	1.14*	1.09 - 1.18	0.99	0.95 - 1.03	0.89	0.76 - 1.05	0.92	0.78 - 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 - 1.33	1.02	1.00 - 1.04	1.31*	1.29 - 1.33	1.03*	1.01 - 1.05	1.10*	1.04 - 1.17	0.93	0.87 - 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 - 0.93	1.21*	1.19 - 1.24	0.92*	0.91 - 0.94	1.21*	1.19 - 1.23	0.91*	0.86 - 0.96	1.09*	1.02 - 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 - 0.83	0.74*	0.73 - 0.76	0.82*	0.80 - 0.83	0.74*	0.73 - 0.76	0.84*	0.80 - 0.89	0.80*	0.75 - 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 - 2.38	1.75*	1.71 - 1.79	2.42*	2.38 - 2.47	1.76*	1.72 - 1.79	1.68*	1.50 - 1.88	1.56*	1.38 - 1.76

[a]BAC: Blood alcohol concentration

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

Discussions

To ascertain 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 populations. 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 can therefore be 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 while 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 head-injury related hospitalisation not only for bicyclists but also for motorcyclists.

The current research is limited by the fact that death data are not explicitly recorded in the NHIRD. Patients would die even if they are hospitalised. Unfortunately no such data is available from the NHIRD – these patients are recorded as "hospitalisation" instead of "deaths". Future research may attempt to obtain death data that are unavailable from the NHIRD, which would open up 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 the adjustment of this result for other factors in the multivariate analysis, bicyclists have lower risks of hospitalisation. The results here 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 purpose and 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 bicyclists and motorcyclists. The result here adds to existing literature of motorcycle and bicycle road safety by concluding that diminished light conditions are associated not only with accident occurrence [25,26] but also with head injury-related hospitalisation. It seems clear here that enhancing conspicuity, in particular in diminished light conditions, may be an effective countermeasure to reduce both

accident risk 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. (2001)[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 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 (e.g., electric bicycles that now in general may travel at more than 25 km/h[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 that concluded that compared with riders in cities, riders in rural areas were 7 times less likely to wear helmets. In addition, a national survey administrated by the HPA[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 revealed 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 dominated transportation mode and there has been a rapid increase in cycling including bikeshare bicycles. The results derived in the current research, therefore, are most generalizable to other countries where there is similar traffic composition.

Unanswered questions remained in the current research include what other factors may affect hospitalisation due to head injuries among bicyclists and motorcyclists. Future research may attempt to obtain these 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 electronic device use (e.g., phone and MP3 players) that have been increasingly used when riding.

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Pai CW contributes to data analysis, interpretation of the data, and final approval of the version to be published.

Chen YC contributes to data analysis, and final approval of the version to be published.

Lin HY contributes to the design of the work, data analysis, interpretation of the data, drafting the manuscript and final approval of the version to be published.

Chen PL contributes to the design of the work, data analysis, interpretation of the data, drafting the manuscript and final approval of the version to be published.

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372 Science Center, Ministry of Health and Welfare, Taiwan.

373 The National Traffic Accident Dataset and the National Health Insurance Research Database 374 (NHIRD), which are open to the researchers in Taiwan, are available from the Health and 375 Welfare Data Science Center (http://dep.mohw.gov.tw/DOS/np-2497-113.html). Only citizens 376 of Taiwan who fulfil the requirements of conducting research projects are eligible to apply for 377 the NHIRD and National Traffic Accident Dataset. The use of NHIRD and National Traffic 378 Accident Dataset are limited to research purposes only. Applicants must follow the 379 Computer-Processed Personal Data Protection Law.

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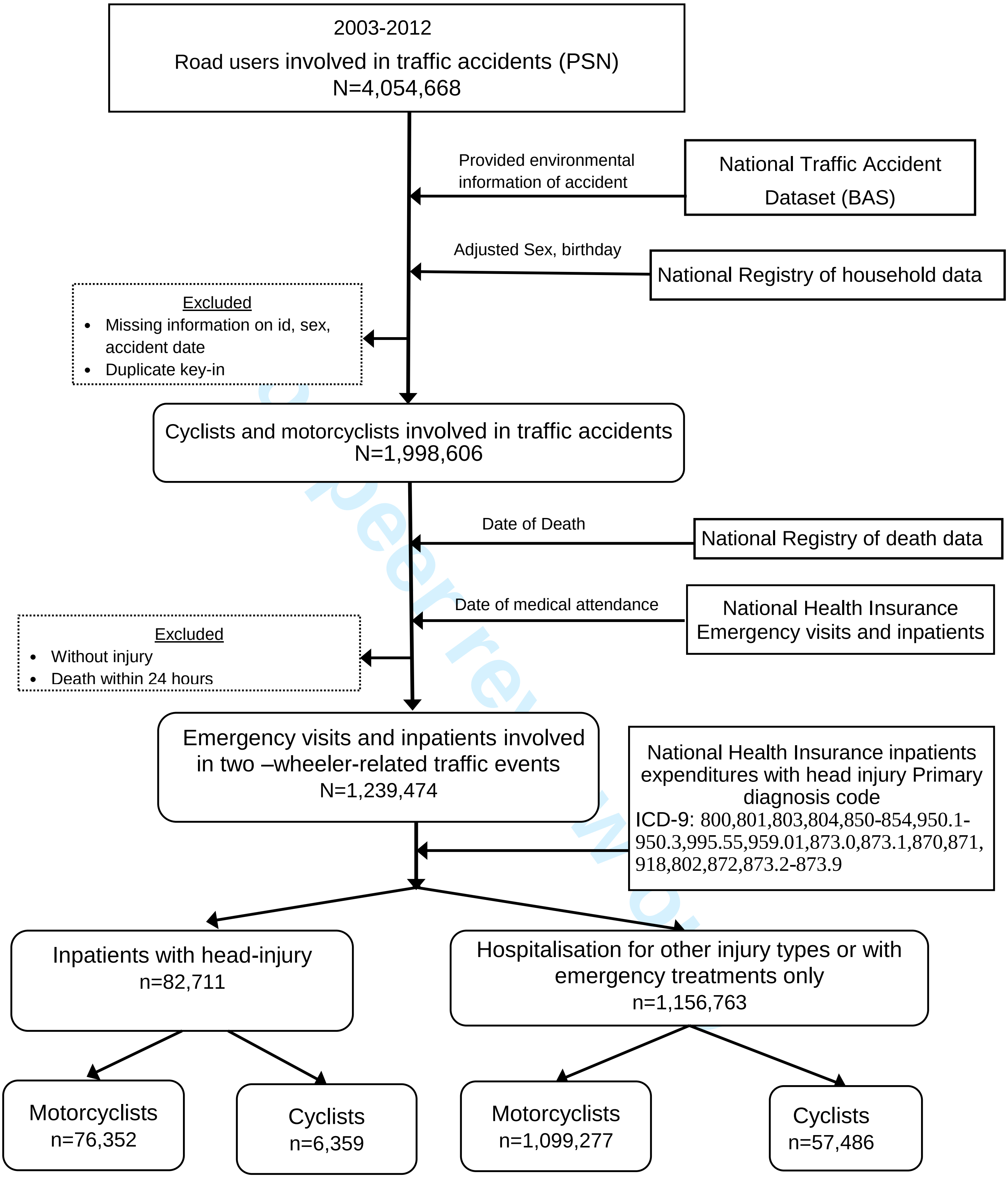
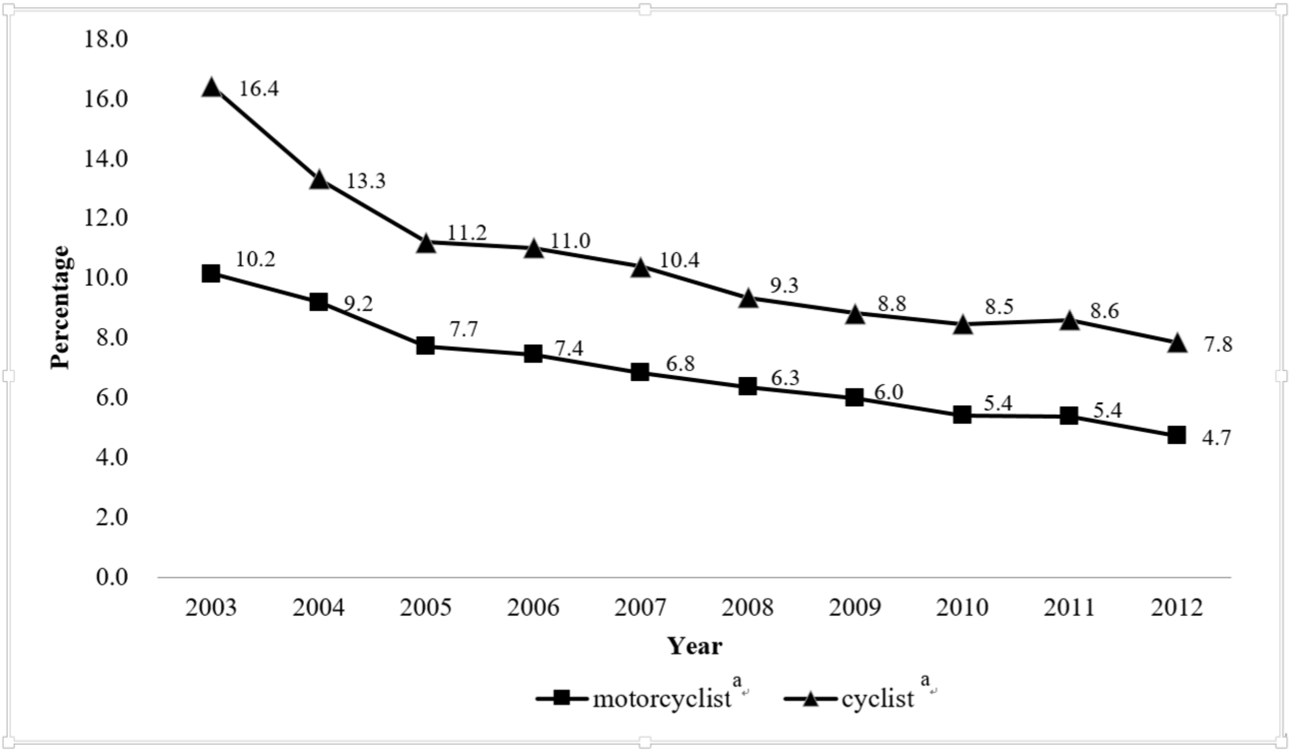


Appendix 1. Study flow diagram



Appendix 2. Trend of head injuries among two-wheeler riders involved in all emergency and inpatient visits for two-wheeler traffic accidents.

[a] :significantly decreasing according to the Mann-Kendall trend test

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	8-10
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	9-10
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	10-11
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8-11
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	9-10
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-11
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	11-12
		(*b*) Describe any methods used to examine subgroups and interactions	N/A
		(*c*) Explain how missing data were addressed	11-12
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	9-10

(*e*) Describe any sensitivity analyses	N/A

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9-10
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	Appendix 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	13
		(b) Indicate number of participants with missing data for each variable of interest	8
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	*8-9, 11*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	15-26
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	26-30
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	30
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	30
Generalisability	21	Discuss the generalisability (external validity) of the study results	30
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	31

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.