



Evaluation of injuries sustained by motorcyclists in approach-turn crashes in Taiwan



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ABSTRACT

Objectives: In western countries, a typical car-motorcycle crash occurs at an intersection where a car manoeuvres into the path of an oncoming motorcycle, which involves a car driver violates motorcycle's right of way (ROW). In Taiwan, however, a unique type of crash (approach-turn crash) occurs when a turning (including U-turn) motorcycle frequently infringes upon a car's ROW. The primary objective of this study was to examine injuries sustained by motorcyclists in this unique type of crash.

Method: Using the linked data from the National Taiwan Crash Database and the National Health Insurance Research Data from 2003 to 2015, this study examined several anatomical injuries (e.g., head and face, neck, chest and abdomen, spine, and lower extremities), as well as the resulting injury severity (e.g., death within 30 days, hospitalisation, and emergency visit only/outpatient, and length of hospital stay). Variables examined include demographic data (sex, age, alcohol use, license status, and helmet use), vehicle attributes (engine size, type of crash partner, and crash type), road and environmental factors (curvature, crash location, day of week and time of crash). Injuries sustained by motorcyclists in an approach-turn motorcycle-turning crash (motorcycle is a ROW violator) were compared with those sustained by motorcyclists in an approach-turn car-turning crash (car is the ROW violator).

Results: A total of 21,919 motorcyclists were enrolled, of whom 18,041 and 3878 were motorcyclists involved in approach-turn car-turning and motorcycle-turning crashes, respectively. The percentage of death within 30 days; hospitalisation; length of hospital stay; and injuries to the head and face, neck, and chest and abdomen were significantly higher for motorcyclists in approach-turn motorcycle-turning crashes. Results of logistic regression models revealed that riding under the influence of alcohol and riding without a licence were associated with death/hospitalisation, and injuries to particular body regions (head and face, neck, and chest and abdomen). Helmet use was associated with a decreased likelihood of head and face and neck injuries.

Conclusion: Motorcyclists tended to be more severely or fatally injured and had increased head and face, neck, and chest and abdomen injuries when they were ROW violators than when their ROWs were violated at an intersection. Efforts to curb drunk riding and unlicensed riding may constitute effective intervention points.

1. Introduction

According to official statistics in Taiwan in year 2016 (MOTC, 2017), there are a total of 13,690,684 registered motorcycles, with the equivalent of 378 motorcycles/km². The number of motorcyclist casualties resulting from road crashes reaches 339,404. Motorcyclist fatalities contribute to the most traffic deaths, accounting for 62.7% of all fatalities in year 2016 (MOTC, 2017). Motorcycle crashes in Taiwan result in huge burden on emergency room treatments and medical resources.

Lower extremity injuries have been among the most common injuries sustained by motorcyclists, followed by upper extremity and head

injuries (Peek-Asa et al., 1994; Jeffers et al., 2004; Hefny et al., 2012; Serre et al., 2012). Head, chest, and abdominal injuries, however, have tended to be more severe (Serre et al., 2012; Hanna and Austin, 2008). (Peek-Asa et al., 1994) investigated the effects of crash type on anatomical injuries and reported that multi-vehicle crashes posed a higher risk of lower extremity injuries than did single-motorcycle crashes. Furthermore, (Moskal et al., 2007) indicated that compared with individuals involved in single-motorcycle crashes, those colliding with a fixed object had a higher risk of head, facial, chest, and abdominal injuries. Motorcyclists involved in approach-turn crashes (where a turning car violated the right of way [ROW] of an oncoming motorcycle) were most likely to sustain severe extremity injuries compared

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with those involved in other crash configurations, except for head-on collisions (Peek-Asa et al., 1994; Moskal et al. (2007)).

Prior to widespread helmet use, head injuries sustained by motorcyclists were a common cause of considerable morbidity and mortality. Research has consistently suggested that motorcycle helmet use and its related laws have successfully reduced head injuries, thus reducing fatalities among motorcyclists (Liu et al., 2008). A similar reduction in head injuries, hospitalisation due to head injuries, and fatalities because of helmet use has been reported in some developing countries, such as Malaysia (Supramaniam et al., 1984), Vietnam (Passmore et al., 2010), and Taiwan (Pai et al., 2017), and in developed countries, such as the United States (Peng et al., 2017) and Italy (Servadei et al., 2003). Although it has been argued that helmet use may increase neck injuries (Goldstein, 1986), helmet use does not appear to increase the risk of neck injury and may provide some protective advantage (Page et al., 2018; Crompton et al., 2011; Rice et al., 2016).

Injuries sustained by motorcycle riders in approach-turn crashes at an intersection may tend to be severe. Using the linked data from the police-reported data and hospital data in California, the United States, (Peek-Asa and Kraus (1996)) reported that motorcyclists in approach-turn crashes had increased lower extremity and abdominal injuries. Furthermore, the authors indicated that motorcyclists' average injury severity score (ISS), percentage fatally injured, and average number of hospital days were higher in approach-turn crashes, where car drivers are ROW violators, than in other types of crashes, except for head-on crashes. (Peek-Asa and Kraus (1996)) concluded that injuries sustained by motorcyclists in approach-turn crashes where motorcyclists were ROW violators were not as severe as those sustained by motorcyclists where left-turning car drivers were ROW violators. In line with the results reported by (Peek-Asa and Kraus (1996)), (Pai and Saleh (2007), 2008) analysed UK Stats19 accident data and indicated that approach-turn car-turning crashes caused more severe injuries than approach-turn motorcycle-turning crashes. By analysing police-reported crash data in Taiwan, (Chen et al. (2018a)) indicated that the fatality rate was higher among motorcyclists when they were ROW violators in approach-turn crashes compared with when motorists were ROW violators (1.48% vs. 0.53%).

Studies (e.g., (Pai and Saleh, 2007, 2008)) conducted in developed countries have suggested that injuries sustained by motorcyclists in approach-turn car-turning crashes tended to be more severe than injuries sustained by motorcyclists in approach-turn motorcycle-turning crashes. However, according to the findings reported by (Chen et al. (2018a)), such an effect appears to be different in Taiwan where motorcyclists tend to sustain more severe injuries when they are ROW violators in such crashes. In an extension of the study conducted by (Chen et al. (2018a)), the primary aim of this study was to investigate whether motorcyclists have an increased injury severity when they are ROW violators compared with when motorists are ROW violators. In addition, this study also aims to examine the determinants of motorcyclist injury severity, as well as anatomical injuries, among motorcyclists involved in approach-turn crashes.

2. Materials and methods

2.1. Data source

The current research used and linked two datasets, the National Traffic Crash Dataset 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. The National Police Agency, Taiwan, is in charge of recording and maintaining the National Crash Traffic Dataset. Police crash investigation teams complete crash report forms that comprise crash, vehicle, and victim files. In the crash file, general information such as the times and dates of crashes, road type, speed

limit, and lighting, road, and weather conditions are recorded. Vehicle and victim files contain variables such as vehicle type, first point of vehicle impact, vehicle manoeuvres, and human attributes such as age, gender, and helmet use.

The Bureau of National Health Insurance (BNHI) in Taiwan implemented the National Health Insurance (NHI) programme on March 1, 1995. The NHIRD, which covers 99% of the population in Taiwan, comprises the outpatient and inpatient claims data of all NHI beneficiaries, and all hospitals and clinics are required to report to the BNHI on a monthly basis.

The following data are available in the NHIRD: patients' age and sex, admission and discharge dates, care location, hospital level, treatment department, surgical procedures, medical expenditures, injury severity indicators (hospitalisation, injury severity score, length of hospital stay, and death within 30 days), diagnosis of disease or injury (in accordance with the 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 data were extracted using ICD-9-CM N-codes ranging from 800 to 900, that report principal diagnoses for injuries. The encrypted identification numbers of patients were used to link the NHIRD externally to the National Traffic Crash Dataset. The present study was exempted from review by an institutional review board (IRB no#: 201,409,033) because no individual patient or casualty can be identified.

A flow chart of sample selection from the two datasets for the period from 2003 to 2015 is presented in Fig. 1. A total of 6,050,966 casualties involved in motor vehicle crashes were extracted from the National Traffic Crash Dataset. After missing data on identification numbers, sex, accident date ($n = 411,281$), and duplicate cases ($n = 12,909$) had been removed, a total of 5,626,776 casualties remained. Subsequently, casualties that were identified as motorcyclists ($n = 2,939,554$) were enrolled. This study focused on two-vehicle motorcycle-car crashes where the crash partner could be a car, taxi, heavy goods vehicle, or bus/coach. Crashes that involved three vehicles or more, or crashes that involved a pedestrian, bicyclist, or motorcyclist as the crash partner were excluded ($n = 1,444,885$). In addition, crashes classified as types of multi-veh crash other than approach-turn crashes ($n = 1,068,909$), crashes classified as single-motorcycle crashes ($n = 215,064$), and crashes that could not be classified into any crash type ($n = 188,777$) were excluded. After removing these cases, the National Traffic Crash Dataset was merged with the NHIRD (E810–E825) by using patients' IDs and crash dates—those with the same IDs and crashes that occurred on the same dates were matched and merged. Those whose IDs or crash dates could not be matched ($n = 1626$) were excluded, resulting in a total of 21,919 valid cases for motorcycle approach-turn crashes. Of the 21,919 approach-turn crashes, 18,041 involved a left-turning car violating the ROW of oncoming motorcycles and 3878 involved a left-turning motorcycle violating the ROW of oncoming vehicles. Injury severity included death within 30 days ($n = 143$), hospitalisation ($n = 3353$), and emergency visit only or outpatient treatment ($n = 18,423$).

2.2. Definition of variables

The following demographic data were collected for casualties: sex; age (four groups: < 18 , 18–40, 41–64, and ≥ 65 years); blood alcohol consumption level (no: $\leq 0.03\%$ or yes: $> 0.03\%$); license status (licensed: with a valid license or unlicensed: without a valid license); and helmet use (yes or no). Vehicle attributes included the engine size (≤ 50 cc, 51–250, and > 250 cc) and crash partner (car, taxi, heavy vehicles including bus/coach or heavy goods vehicle, and others). The following road and environmental factors were considered: curvature (straight road and horizontal/vertical curvature: uphill/downhill/bend road); crash location (rural: roadways with speed limits of ≥ 51 km/h, and urban: roadways with speed limits of ≤ 50 km/h); day of week (weekday and weekend); and time of crash (daytime: 0600–1759 and

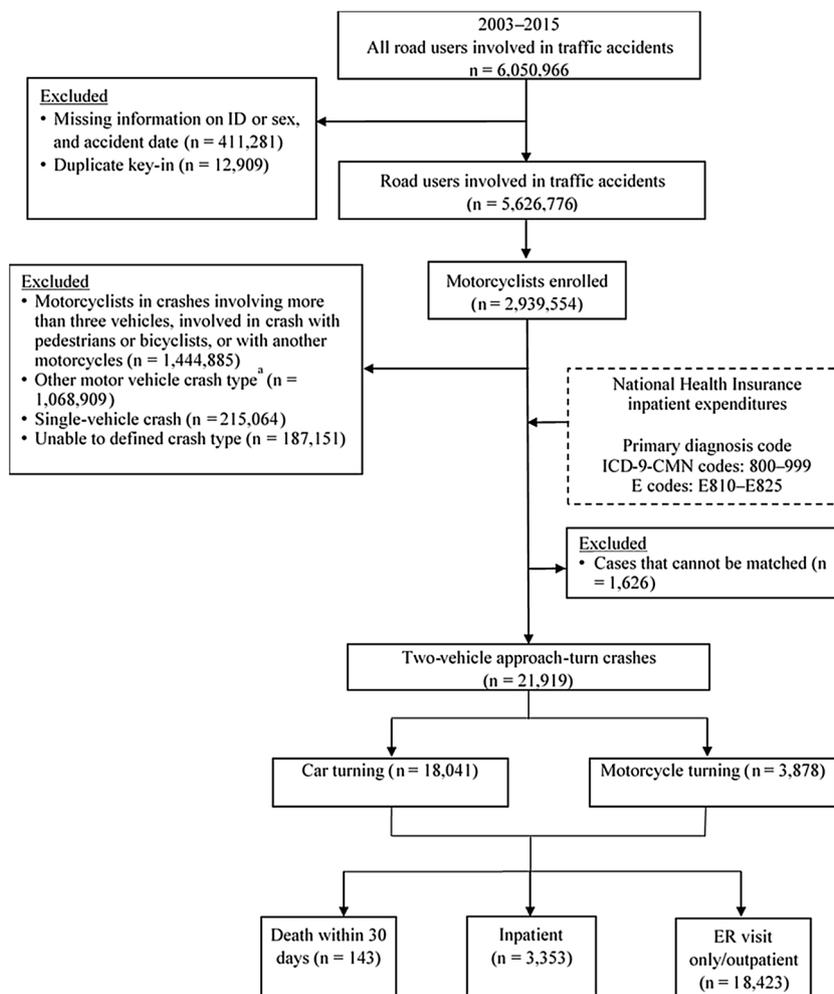


Fig. 1. Study flow-chart. a: Other types of crashes included head-on, rear-end, angle, and sideswipe crashes.

evening/night: 1800–0559). The urban/rural classification has been widely adopted in Taiwan (see the study (Liu et al., 2006)): rural roadway is for speed limit of 51 km/h or above, and urban roadway is for speed limit up to 50 km/h.

Motorcycle approach-turn crashes examined were classified into two types of crashes, on the basis of whether the left-turning vehicle was a motorcycle or a car (see Fig. 2 for a schematic illustration of these two types of ROW crashes). The turning vehicle was considered to be either turning left or making a U-turn manoeuvre. An approach-turn car-turning crash is defined as a crash in which a left-turning car violates the ROW of an approaching motorcycle. An approach-turn

motorcycle-turning crash is defined as a crash in which a left-turning motorcycle violates the ROW of an approaching car (including car, taxi, and bus/coach).

2.3. Analysis

Distribution of injury severity by a set of variables (e.g., human attributes, environmental factors, and vehicle characteristics) is firstly reported. Chi-square tests are conducted for examining the association between the independent variables and injury severity. In our study, to minimise type II errors in variable selection and biased inferences

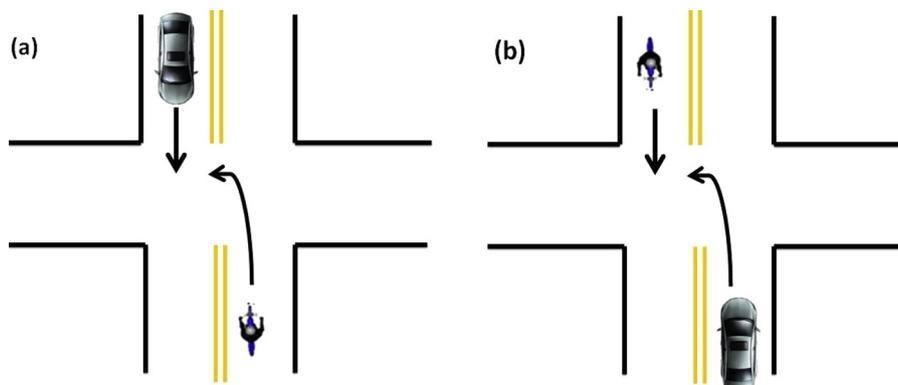


Fig. 2. Schematic diagram of the two types of ROW crashes (a: approach-turn motorcycle-turning crash; b: approach-turn car-turning crash).

(Mickey and Greenland, 1989; Maldonado and Greenland, 1993), any variable with $p < 0.2$ in the chi-squared tests was incorporated into the multivariate analysis. We base this on the p -value cut-off point of 0.2 that is a conventional level adopted in literature (e.g., (Chien et al., 2017; Chen et al., 2018b)). Injuries to different body regions (i.e., head/face, neck, chest/abdomen, spine, and extremities) between these two types of crashes were also compared. Odds of anatomical injuries among motorcycle riders involved in the two types of crashes were estimated using stepwise logistic regression models after a set of variables had been controlled for. Chi-square independent test and Cramer's V were estimated to assess multicollinearity among the variables.

In our study, when estimating multivariate logistic models, there are two strategies for assigning a reference group for each variable: use the normative group or the largest category. For example, we have a variable alcohol use (yes vs. no): the more normative and large motorcycle riders were not influenced by alcohol (in our data, 98.96% of motorcyclists were not influenced by alcohol). The interesting comparison is to examine how intoxicated motorcyclists differ from this normative group (i.e., sober motorcyclists) with regard to injury outcome. Another example in our study is those aged 18–40 that were used as the reference category. There were two reasons for such an assignment. First, there seems to be no normative group for us to choose a reference in a logical sense. Therefore, we just used the largest category as the reference. In our data, 68.16% of all motorcyclists were aged 18–40. Second, those aged 18–40 were used as the reference category because it makes interpretation of results easier. In past studies of behaviours and crash outcomes, young motorcyclists were found to be more prone to commit risk-taking behaviours (Chen et al. (2018a)); and elderly motorcyclists tended to sustain more severe injuries compared to any other age group of motorcyclists (Pai et al., 2017). In our study, the interesting comparison is to investigate how young/elderly motorcyclists differ from this age group (18–40) regarding injury outcomes.

3. Results

3.1. General results

As presented in Table 1, the number of approach-turn car-turning crashes was higher than that of approach-turn motorcycle-turning crashes, with the ratio of these two types of crashes being 4.65: 1 ($n = 18,041$ vs. $n = 3878$). Motorcyclists involved in approach-turn motorcycle-turning crashes had a significantly higher average percentage of deaths within 30 days and hospitalisation (1.39% vs. 0.49%, and 19.57% vs. 14.38%, respectively). Of those diagnosed to be hospitalised ($n = 3353$), the average length of hospital stay for motorcyclist patients involved in approach-turn motorcycle-turning crashes is 9.19 days, which is significantly higher than those in approach-turn car-turning crashes (7.86 days).

A majority of approach-turn crashes involved male motorcyclists (65.19%), male motorists (78.30%), helmeted motorcyclists (91.11%), motorcycle riders and motorists aged between 18–40 (68.16% and 51.95%, respectively), motorcycle riders and motorists with valid license (87.03% and 96.71%), motorcycles with engine size 51–250cc (86.96%), sober motorcyclists and drivers (95.24% and 96.33%, respectively), cars (73.82%), and occurred during daytime (64.23%), on roadways with speed limit < 50 km/h (92.19%), on straight roadways (97.81%), and on weekdays (74.83%).

3.2. Model estimation results

Multivariate stepwise logistic regression models were used to estimate the odds of motorcyclist injury severity after other variables had been controlled for (Table 2). Note here that the category “death within 30 days” ($n = 143$) is merged with the category “hospitalisation” when estimating regression models, primarily due to two reasons. First, when

examining death and hospitalisation together, the model was more parsimonious than when examining deaths and hospitalisation separately in the model. In addition, when examining deaths and hospitalisation separately in the model, there appears fewer variables that were statistically significant. Second, the primary aim of the study was to investigate the influential factors on severe injury outcomes that result from approach-turn crashes. Two groups of patients were considered: patients who required hospitalisation for further medical treatments; and patients who required hospitalisation for further medical treatments but subsequently died within 30 days. These two groups of patients both required hospitalisations due to severe injuries, and thus we suppose that it is appropriate to merge deaths and hospitalisations.

As shown in Table 2, risk factors for death and hospitalisation (relative to emergency visit only/outpatients) included approach-turn motorcycle-turning crashes (adjusted OR [AOR] = 2.77), male motorcyclists (AOR = 3.42), motorcyclists aged < 18 years (AOR = 2.67), crashes occurring on rural roadways (AOR = 2.84), riding on a vertical/horizontal curvature (AOR = 2.32), crashes occurring during evening or mid-night hours (AOR = 1.42), riding unlicensed (AOR = 3.52), riding a moped with an engine size of up to 50 cc (AOR = 1.23), riding a motorcycle intoxicated (AOR = 5.25), and colliding with a heavy vehicle (AOR = 2.90). Motorcyclists had a decreased odds of death and hospitalisation (OR = 0.63) when they wore helmet.

3.3. Injuries to body regions

Injuries to various body regions among motorcyclists were compared between approach-turn motorcycle-turning crashes and approach-turn car-turning crashes. As reported in Table 3, lower extremity (31.37%) were the most common injury regions, followed by the head and face (8.98%). Motorcyclists in approach-turn motorcycle-turning crashes had a significantly higher percentage of certain anatomical injuries than did motorcyclists in approach-turn car-turning crashes: head and face (9.10% vs. 7.46%), neck (6.21% vs. 4.07%), and chest and abdomen injuries (2.94% vs. 2.02%). Though not significantly different, motorcyclists had a higher percentage of spine and lower extremity injuries when they were ROW violators compared to when their ROWs were violated (0.77% vs. 0.58%; 39.81% vs. 29.55%).

The odds of injuries to the head and face, neck, and chest and abdomen among motorcyclists in the two types of crashes were estimated using multivariate stepwise logistic regression models (Tables 4–6). As shown in Table 4, risk factors for head/face injuries included approach-turn motorcycle-turning crashes (AOR = 1.58), male motorcyclists (AOR = 1.51), motorcyclists aged < 18 years (AOR = 1.48), riding while intoxicated (AOR = 1.36), riding unlicensed (AOR = 1.34), and riding a moped with an engine size of up to 50 cc (AOR = 1.33). Wearing a helmet while riding appeared to be a protective factor for head/face injuries (AOR = 0.43).

Table 5 lists the results of the multivariate logistic regression model for neck injuries. Risk factors found to be associated with neck injuries included approach-turn motorcycle-turning crashes (AOR = 1.20), male motorcyclists (AOR = 1.46), motorcyclists aged < 18 years (AOR = 1.26), riding unlicensed (AOR = 1.93), and riding a moped with an engine size of up to 50 cc (AOR = 1.25). Wearing a helmet while riding appeared to be a protective factor for neck injuries (AOR = 0.79).

The odds of chest and abdomen injuries among motorcyclists in approach-turn crashes were estimated using multi-variate logistic regression after several variables that predict both crash and injury types had been controlled for (Table 6). Similar to head or face and neck injuries, an increased odds of chest and abdomen injuries was noted in those involved in approach-turn motorcycle-turning crashes (AOR = 1.73). In addition, male motorcyclists (AOR = 1.28), elderly motorcyclists (AOR = 2.75), and unlicensed motorcyclists (AOR = 1.45) had a higher likelihood of sustaining chest and abdominal injuries.

Table 1
Distribution of pedestrian injury severity for the period 2003–2015.

	N	Death n(%)	Hospitalisation n(%)	ER visit only/outpatient n(%)	χ^2 test p-value
Total	21919	143(0.65)	3353(15.30)	18,423(84.05)	
Motorcyclist gender					
Female	7630(34.81)	12(0.16)	1183(15.50)	6435(84.34)	p < 0.01
Male	14289(65.19)	131(0.92)	2170(15.19)	11,988(83.90)	
Driver gender					
Female	4757(21.70)	16(0.34)	626(13.16)	4115(86.50)	p < 0.01
Male	17162(78.30)	127(0.74)	2727(15.89)	14,308(83.37)	
Motorcyclist age					
< 18	782(3.57)	11(1.41)	159(20.33)	612(78.26)	p < 0.01
18-40	14940(68.16)	74(0.50)	1839(12.31)	13,027(87.20)	
41-64	4954(22.60)	25(0.50)	996(20.10)	3933(79.39)	
65 +	1243(5.67)	33(2.65)	359(28.88)	851(68.46)	
Driver age					
< 18	12(0.05)	0(0)	4(33.33)	8(66.67)	p = 0.584
18-40	11386(51.95)	77(0.68)	1671(14.68)	9638(84.65)	
41-64	9666(44.10)	61(0.63)	1547(16.00)	8058(83.36)	
65 +	855(3.90)	5(0.58)	131(15.32)	719(84.09)	
Approach turn type					
Car turning	18041(82.31)	89(0.49)	2594(14.38)	15,358(85.13)	p < 0.01
Motorcycle turning	3878(17.69)	54(1.39)	759(19.57)	3065(79.04)	
Motorcyclist license					
Licensed	19076(88.12)	100(0.52)	2662(14.95)	16,314(85.52)	p < 0.01
Unlicensed	2571(9.83)	37(1.44)	628(24.43)	1906(74.13)	
Driver license					
Licensed	21197(97.36)	129(0.61)	3201(15.14)	17,867(84.29)	p < 0.01
Unlicensed	575(2.64)	11(1.91)	128(22.26)	436(75.83)	
Motorcyclist engine size					
51–249cc	19061(86.96)	118(0.62)	2793(14.65)	16,150(84.73)	p < 0.01
250cc or above	108(0.49)	2(1.85)	17(15.74)	89(82.41)	
Up to 50cc	2750(12.55)	23(0.84)	543(19.75)	2184(79.42)	
Motorcyclist alcohol use					
No	20875(98.96)	78(0.37)	3080(14.75)	17,717(84.87)	p < 0.01
Yes	414(1.94)	11(2.66)	91(21.98)	312(75.36)	
Driver alcohol use					
No	21114(98.51)	133(0.63)	3219(15.25)	17,762(84.12)	p = 0.05
Yes	320(1.49)	3(0.94)	64(20.00)	253(79.06)	
Vehicle types involved					
Car	16181(73.82)	72(0.44)	2311(14.28)	13,798(85.27)	p < 0.01
Taxi	1943(8.86)	5(0.26)	208(10.71)	1730(89.92)	
Heavy vehicle	3682(16.80)	63(1.71)	807(21.92)	2812(76.37)	
Others	113(0.52)	3(2.65)	27(23.89)	83(73.55)	
Time of crash					
Daytime	14078(64.23)	74(0.53)	2342(16.03)	11,662(82.84)	p < 0.01
Evening	7841(35.77)	69(0.89)	1011(12.89)	6761(86.23)	
Crash location					
Urban	20207(92.19)	105(0.52)	2914(14.42)	17,188(85.06)	p < 0.01
Rural	1712(7.81)	38(2.22)	439(25.64)	1235(72.14)	
Occurring on roadways with vertical or horizontal curvature					
Straight	21440(97.81)	134(0.63)	3264(15.22)	18,042(84.15)	
Vertical/horizontal	479(2.19)	9(1.88)	89(18.58)	381(79.54)	
Occurring on weekends or weekdays					
Weekday	16401(74.83)	96(0.59)	2557(15.59)	13,748(83.82)	p = 0.01
Weekend	5518(25.17)	47(0.85)	796(14.43)	4675(84.72)	
Motorcyclist helmet use					
Yes	19971(91.11)	95(0.48)	3009(15.07)	16,867(84.46)	p < 0.01
No	1948(8.89)	48(2.46)	344(17.66)	1556(79.88)	

4. Discussion and conclusion

The results of the present study revealed that in Taiwan, the number of approach-turn car-turning crashes was higher than that of approach-turn motorcycle-turning crashes, with the ratio being 4.65: 1. The prevalence of approach-turn car-turning crashes was relatively higher than that of approach-turn motorcycle-turning crashes in Western countries; for example, it was 25: 1 in the United States (Peek-Asa and Kraus, 1996) and 16:1 in the United Kingdom (Pai and Saleh, 2007). In addition, injury severity patterns associated with motorcycle approach-

turn crashes in Taiwan appear to be different from those in Western countries. For instance, we found that motorcyclists had an increased injury severity (i.e., a higher likelihood of death within 30 days, hospitalisation, and longer length of hospital stay) when they were ROW violators than when their ROWs were violated by a turning car. Such a finding appears to contradict the findings reported by (Peek-Asa and Kraus, 1996) that motorcycle riders tended to be more fatally or severely injured when their ROWs were violated than when they were ROW violators. We found that injuries to the head and face, neck, and chest/abdomen were significantly higher for motorcyclists who were

Table 2
Adjusted odds ratio of death and hospitalisation.

	β	S.E.	AOR (95%CI)
Intercept	-6.22	0.38	
Approach-turn motorcycle turning vs. Approach-turn car turning	1.02	0.21	2.77(1.84~4.19)
Motorcyclist's sex (male vs. female)	1.23	0.35	3.42(1.72~6.79)
Motorcyclist's age (ref.: 18 – 40 years)			
< 18	0.98	0.39	2.67(1.23~5.80)
41 – 64	-0.23	0.33	0.79(0.41~1.53)
65+	0.70	0.33	2.01(1.05~3.84)
Occurring on rural roadways (ref.: urban)	1.04	0.27	2.84(1.67~4.83)
Occurring on roadway (ref.: straight)			
Horizontal/vertical	0.78	0.53	2.18(0.77~6.22)
Helmet use (ref.: non-use)	-0.47	0.20	0.63(0.42~0.92)
Occurring at evening/midnight	0.35	0.14	1.42(1.08~1.87)
Motorcyclist unlicensed (ref.: licensed)	1.26	0.41	3.52(1.57~7.87)
Motorcyclist's alcohol use (Yes vs. no)	1.66	0.37	5.25(2.56~10.77)
Engine size (ref.: 51 – 250cc)			
> 250cc	-0.11	0.44	0.90(0.38~2.11)
≤ 50 cc	0.21	0.07	1.23(1.07~1.41)
Vehicle type (ref.: car)			
Taxi	-0.80	0.73	0.45(0.11~1.87)
Heavy vehicle	1.06	0.24	2.90(1.80~4.65)
Others vs. car	-0.29	0.18	0.75(0.53~1.06)

Hosmer-Lemeshow goodness fit test with p-value = 0.248.

ROW violators than for motorcyclists whose ROWs were violated. This can explain why motorcyclists had an increased injury severity when they were ROW violators. In Taiwan, such a unique type of crash (i.e., motorcyclist as an ROW violator) poses a safety impact to motorcyclists with regard to crash occurrences and consequences.

To deter motorcyclists from turning left in front of approaching cars at intersections, a mandatory hook-turn zone is an engineering measure that has been implemented in Taiwan for decades. Motorcycle riders intending to execute a left-turn manoeuvre are directed to wait at such a hook-turn zone, and subsequently proceed to their intended directions. Not using the hook-turn zone has been identified as the most frequent traffic violation among motorcyclists in Taiwan (Pai et al., 2013). Intervention points may first attempt to prevent this unique crash type from occurring by enforcing a mandatory hook-turn zone.

Several findings are worth being discussed. For example, in accordance with the literature (e.g., (Liu et al., 2008; Gopalakrishna et al., 1998)), we found that helmet use was associated with decreased odds of death/hospitalisation and head or face injuries. Furthermore, our finding related to the effect of helmet use on neck injuries is congruent with the findings of past studies (Page et al., 2018; Crompton et al., 2011; Rice et al., 2016) that helmet use may provide some neck protection.

Using the same linked data from the National Traffic Crash Dataset and the NHIRD, (Pai et al. (2017)) reported that traumatic brain injury was the most common anatomical injury among all motorcyclist patients. By using the same linked data, we further found that injuries to lower extremities were the most common among those in the two types of ROW crashes. In addition, the percentage of lower extremity injuries was higher among motorcyclists who were ROW violators than among

Table 3
Injuries to body regions among motorcyclists in the two types of ROW crashes for the period from 2003 to 2015.

Crash type	N	Head and face ²		Neck ²		Chest and abdomen ²		Spine ²		Lower extremities ²	
		n	%	n	%	n	%	n	%	n	%
Approach-turn car turning	18041	1345	7.46	735	4.07	365	2.02	104	0.58	5331	29.55
Approach-turn motorcycle turning	3878	353 ¹	9.10	241 ¹	6.21	114 ¹	2.94	30	0.77	1544 ¹	39.81
Total	21919	1698	8.98	976	4.45	479	2.19	134	0.61	6875	31.37

¹ p < 0.05 compared with approach-turn car-turning crashes.

² Injury that needs the highest medical expense.”.

Table 4
Adjusted odds ratio of head and face injuries.

	β	S.E.	AOR (95%CI)
Intercept	-1.56	0.39	
Approach-turn motorcycle turning	0.46	0.12	1.58(1.25~2.00)
Male motorcyclist	0.41	0.09	1.51(1.26~1.80)
Motorcyclist's age (ref.: 18 – 40 years)			
< 18	0.39	0.17	1.48(1.26~1.73)
41 – 64	-0.36	0.11	0.69(0.56~0.87)
65+	0.21	0.10	1.23(1.01~1.50)
Helmet use (ref.: helmet non-use)	-0.85	0.28	0.43(0.25~0.74)
Motorcyclists alcohol use (ref.: non-use)	0.31	0.15	1.36(1.02~1.83)
Motorcyclists unlicensed (ref.: licensed)	0.29	0.11	1.34(1.08~1.66)
Engine size (ref.: 51 – 250cc)			
251cc or above	-0.24	0.17	0.78(0.56~1.09)
Up to 50cc	0.28	0.10	1.33(1.10~1.61)

Hosmer-Lemeshow goodness fit test with p-value = 0.588.

Table 5
Adjusted odds ratios of neck injuries.

	β	S.E.	AOR (95%CI)
Intercept	-1.14	0.07	
Approach-turn motorcycle turning	0.18	0.08	1.20(1.02~1.40)
Male motorcyclist	0.38	0.15	1.46(1.09~1.96)
Motorcyclist's age (ref.: 18–40)			
< 18	0.23	0.09	1.26(1.06~1.50)
41 – 64	-0.56	0.11	0.57(0.47~0.71)
65+	-0.83	0.20	0.44(0.30~0.64)
Helmet use (ref.: helmet non-use)	-0.23	0.09	0.79(0.67~0.95)
Motorcyclist unlicensed (ref.: licensed)	0.66	0.29	1.93(1.10~3.42)
Engine size (ref.: 51 – 250cc)			
251cc or above	-0.14	0.10	0.87(0.71~1.06)
Up to 50cc	0.22	0.09	1.25(1.04~1.49)

Hosmer-Lemeshow goodness fit test with p-value = 0.507.

Table 6
Adjusted odds ratios of chest and abdominal injuries.

	β	S.E.	AOR (95%CI)
Intercept	-2.80	0.10	
Approach-turn motorcycle turning	0.55	0.15	1.73(1.29~2.33)
Motorcyclist's sex (male vs. female)	0.25	0.10	1.28(1.06~1.56)
Motorcyclist's age (ref.: 18 – 40 years)			
< 18	0.06	0.41	1.07(0.48~2.37)
41 – 64	0.60	0.14	1.83(1.38~2.42)
65+	1.01	0.20	2.75(1.85~4.07)
Motorcyclist unlicensed (ref.: licensed)	0.37	0.15	1.45(1.08~1.94)

Hosmer-Lemeshow goodness fit test with p-value = 0.657.

those whose ROWs were violated, though the difference is not significant. Such a finding is consistent with that reported by (Peek-Asa and Kraus (1996)) who reported that injuries to lower extremities were more frequent among motorcyclists who were turning left than when a car was turning left.

We found that riding under the influence of alcohol and riding

without a licence were significant risk factors for death and hospitalisation, and injuries to the head or face, and neck. (Chen et al., 2018a) concluded that intoxicated motorcyclists and unlicensed motorcyclists contribute to approach-turn motorcycle-turning crashes; thus, efforts directed toward curbing drunk riding and unlicensed riding may constitute effective countermeasures for reducing such crashes and resultant severe injuries.

The linked data analysed in the current research does offer more information, such as traumas and medical treatments that are diagnosed by physicians but unavailable from police crash data, and allows various types of research questions than just using police data alone. Our study, however, has several limitations. First, our data do not include all crashes; instead, our data only include cases that were reported to police for claiming compensation for injury and cases that were treated in hospitals. Those who died at the crash scene and were directly moved to the morgue were not recorded in the NHIRD, and such data were therefore not matched with our police reported data. Our results need to be interpreted with cautions as the die-at-the-scene data were unavailable and not analysed. Second, coding entry error is possible in any dataset and this is beyond the control of this study. Third, both the National Traffic Crash Dataset and the NHIRD are not up-to-date – the latest data available when the current research was conducted were for the period between 2003–2015. Finally, the limitation pertains to the data unavailable in the two datasets; for instance, pre-crash speed of the vehicle, geometric characteristics, or weather conditions, all of which may play a crucial role in injuries to body regions and resultant injury severity.

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References

- Chen, P.L., Pai, C.W., Chen, Y.C., 2018a. Motorcyclist is the right-of-way violator: a population-based study of motorcycle right-of-way crash in Taiwan. *J. Adv. Transp.* 2018, 7 Article ID 9543787.
- Chen, S.J., Chen, C.Y., Lin, M.R., 2018b. Risk factors for crash involvement in older motorcycle riders. *Accid. Anal. Prev.* 111, 109–114.
- Chien, D.K., Hwang, H.F., Lin, M.R., 2017. Injury severity measures for predicting return-to-work after a traumatic brain injury. *Accid. Anal. Prev.* 98, 101–107.
- Crompton, J.G., Bone, C., Oyertunji, T., Pollack, K.M., Bolorunduro, O., Villegas, C., Stevens, K., Cornwell, E.E.3rd., Efron, D.T., Haut, E.R., Haider, A.H., 2011. Motorcycle helmets associated with lower risk of cervical spine injury: debunking the myth. *J. Am. Coll. Surg.* 212 (3), 295–300.
- Goldstein, J.P., 1986. The effect of motorcycle helmet use on the probability of fatality and the severity of head and neck injuries. *Eval. Rev.* 10 (3), 355–375.
- Gopalakrishna, G., Peek-Asa, C., Kraus, J., 1998. Epidemiologic features of facial injuries among motorcyclists. *Ann. Emerg. Med.* 32 (4), 425–430.
- Hanna, R., Austin, R., 2008. Lower-Extremity Injuries in Motorcycle Crashes. NHTSA. NHTSA Technical Report HS-810 982.
- Hefny, A.F., Barss, P., Eid, H.O., Abu-Zidan, F.M., 2012. Motorcycle-related injuries in the United Arab Emirates. *Accid. Anal. Prev.* 49, 245–248.
- Jeffers, R.F., Tan, H.B., Nicolopoulos, C., Kamath, R., Giannoudis, P.V., 2004. Prevalence and patterns of foot injuries following motorcycle trauma. *J. Orthop. Trauma* 18 (2), 87–91.
- Liu, C.Y., Hung, Y.T., Chuang, Y.L., 2006. Incorporating development stratification of Taiwan townships into sampling design of large scale health interview survey. *J. Health Manag.* 4 (1), 1–22.
- Liu, B.C., Ivers, R., Norton, R., Boufous, S., Blows, S., Lo, S.K., 2008. Helmets for preventing injury in motorcycle riders. *Cochrane Database Syst. Rev.* 23 (1), 1469–1493.
- Maldonado, G., Greenland, S., 1993. Simulation study of confounder-selection strategies. *Am. J. Epidemiol.* 138 (11), 923–936.
- Mickey, R.M., Greenland, S., 1989. The impact of confounder selection criteria on effect estimation. *Am. J. Epidemiol.* 129 (1), 125–137.
- Moskal, A., Martin, J.L., Lenguerrand, E., Laumon, B., 2007. Injuries among motorised two-wheelers in relation to vehicle and crash characteristics in Rhone. 20th International Technical Conference on the Enhanced Safety of Vehicles (ESV).
- MOTC, 2017. Traffic Statistics of Year 2016. Ministry of Transportation and Communications, Taiwan, Republic of China.
- Page, P.S., Wei, Z., Brooks, N.P., 2018. Motorcycle helmets and cervical spine injuries: a 5-year experience at a Level 1 trauma center. *J. Neurosurg.* 28 (6), 607–611.
- Pai, C.W., Saleh, W., 2007. Exploring motorcyclist injury severity resulting from various crash configurations at T-junctions in the United Kingdom—an application of the ordered probit models. *Traffic Inj. Prev.* 8 (1), 62–68.
- Pai, C.W., Saleh, W., 2008. Exploring motorcyclist injury severity in approach-turn collisions at T-junctions: focusing on the effects of driver's failure to yield and junction control measures. *Accid. Anal. Prev.* 40 (2), 479–486.
- Pai, C.W., Hsu, J.J., Chang, J.L., Kuo, M.S., 2013. Motorcyclists violating hook-turn area at intersections in Taiwan: an observational study. *Accid. Anal. Prev.* 59, 1–8.
- Pai, C.W., Chen, Y.C., Lin, H.Y., Chen, P.L., 2017. A population-based case-control study of hospitalisation due to head injuries among bicyclists and motorcyclists in Taiwan. *BMJ Open* 7 e018574.
- Passmore, J., Tu, N.T., Luong, M.A., Chinh, N.D., Nam, N.P., 2010. Impact of mandatory motorcycle helmet wearing legislation on head injuries in Viet Nam: results of a preliminary analysis. *Traffic Inj. Prev.* 11, 202–206.
- Peek-Asa, C., Kraus, J.F., 1996. Injuries sustained by motorcycle riders in the approaching turn crash configuration. *Accid. Anal. Prev.* 28 (5), 561–569.
- Peek-Asa, C., Braver, E.R., Shen, H., Kraus, J.F., 1994. Lower extremity injuries from motorcycle crashes: a common cause of preventable injury. *J. Trauma* 37 (3), 358–364.
- Peng, Y., Vaidya, N., Finnie, R., Reynolds, J., Dumitru, C., Njie, G., Elder, R., Ivers, R., Sakashita, C., Shults, R.A., Sleet, D.A., Compton, R.P., CPSTF, 2017. Universal motorcycle helmet laws to reduce injuries: a community guide systematic review. *Am. J. Prev. Med.* 52 (6), 820–832.
- Rice, T.M., Troszak, L., Ouellet, J.V., Erhardt, T., Smith, G.S., Tsai, B.W., 2016. Motorcycle helmet use and the risk of head, neck, and fatal injury: revisiting the Hurt Study. *Accid. Anal. Prev.* 91, 200–207.
- Serre, T., Masson, C., Perrin, C., Martin, J.L., Moskal, A., Llari, M., 2012. The motorcyclist impact against a light vehicle: epidemiological, accidentological and biomechanical analysis. *Accid. Anal. Prev.* 49, 223–228.
- Servadei, F., Begliomini, C., Gardini, E., Giustini, M., Taggi, F., Kraus, J., 2003. Effect of Italy's motorcycle helmet law on traumatic brain injuries. *Inj. Prev.* 9 (3), 257–260.
- Supramaniam, V., van Belle, G., Sung, J.F.C., 1984. Fatal motorcycle accidents and helmet laws in Peninsular Malaysia. *Accid. Anal. Prev.* 16 (3), 157–162.