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Analysis of the injury severity of nonhelmeted motorcyclists colliding with vehicles

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Abstract: To investigate the impact of different factors on the severity of accidents involving nonhelmeted motorcycle riders and different types of vehicles, the 2019 Pakistan traffic accident data was analyzed. The accidents were classified into six types according to the types of vehicles involved: car, bus, truck, bike, motorcycle and rickshaw. Each type of accident was further divided into four severity levels: no injury, minor injuries, major injuries, and fatalities. Twenty variables were selected from five aspects: motorcyclist demographics, roadway, environment, crash, and temporal. Also, six random parameter logit models that considered the heterogeneity of influencing factors were established for each type of accident. The likelihood ratio test and out-of-sample prediction method were used to confirm the non-transferability between different logit models. The results show that all selected variables have significant effects on the severity of accidents; the gender of motorcycle drivers, age, number of lanes, and speeding have the greatest impact. This study can provide a reference for local policymakers to formulate strategies, thereby reducing the severity of collisions between helmetless motorcycle riders and other vehicles.

Key words: road safety; injury severity; random parameters logit model; nonhelmeted motorcyclist collision; out-of-sample prediction

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In 2016, vulnerable road users (e.g., pedestrians, cyclists, and motorcyclists) accounted for roughly half of the 1.35 million deaths caused by road traffic accidents worldwide. In 2016, Motorized two- and three-wheeler riders accounted for about 43% of traffic fatalities in Southeast Asia. Meanwhile, the percentage of all riders in Pakistan who wore standard helmets was only 10.4% [1]. Ref. [2] found that wearing a helmet reduced the risk of head injuries and deaths by 69% and 42%, respectively. Considering that only 10.4% of Pakistani motorcyclists wear helmets, investigating the intrinsic and extrinsic factors that contribute to the severity of accidents involving nonhelmeted riders is essential. This investigation can help mitigate the risks and severity associated with such occurrences. In addition, more effective measures should be implemented to reduce the crash risk for nonhelmeted motorcyclists, who account for most of the population.

Numerous studies have indicated that several factors affect the severity of the injury. Regarding the use of safety equipment, wearing a helmet is associated with a reduced risk of fatal and incapacitating injuries in motorcycle crashes[3]. Other motorcyclist characteristics, such as increasing age[4] and speeding[5], have been found to increase the likelihood of severe and fatal injuries in motorcycle crashes. Because of the vehicle's characteristics, colliding with a heavy vehicle tends to increase the severity of motorcycle accident injuries[6].

However, most studies have focused on motorcycle accidents involving only one vehicle; more efforts should be made to elucidate the severity of injuries caused by nonhelmeted motorcyclists involved in multi-vehicle crashes. In addition, several earlier studies have supported the relationship between the severity of injuries and the type of vehicle in the collision[7-8]. To eliminate the risk propensity in Pakistan's complex traffic flows containing both high- and low-speed vehicles, evaluating the determinants affecting the severity of injuries caused by nonhelmeted motorcyclists in collisions with different vehicle types is crucial.

The complicated interactions between human behavior and other factors such as vehicles, roadways, and environmental attributes may not be adequately represented by detailed data. The absence of certain critical factors can lead to biased results, inconsistent estimation, or ineffective recommendations[9]. The random-parameter approach has proved to be statistically superior in terms of accuracy and reduced heterogeneity and thus has been widely adopted for interpreting unobserved heterogeneity[9]. To account for the heterogeneity in the means and variances in the current study, a series of random-parameter logit models categorized according to the type of involved vehicle is proposed.

This study first describes the dataset and methodologi-

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cal frameworks. Afterwards, estimates are provided for the transferability tests across various vehicle models. The estimated results and marginal effects are then interpreted and discussed. The final section presents the findings and potential future research directions.

1 Data Description

Data on crashes involving nonhelmeted motorcyclists, including motorcyclist demographics, vehicle, roadway, environment, crash, and temporal attributes, were collected from the Rescue 1 122 road traffic accident database in Pakistan.

As indicated in Fig. 1, the dataset included 7 591 motorcycle-vehicle collisions[6]. The severity levels were determined according to the most severe injuries or fatalities involved in the crashes. Substantial differences existed between the numbers and distributions of injury severities across the six model types.

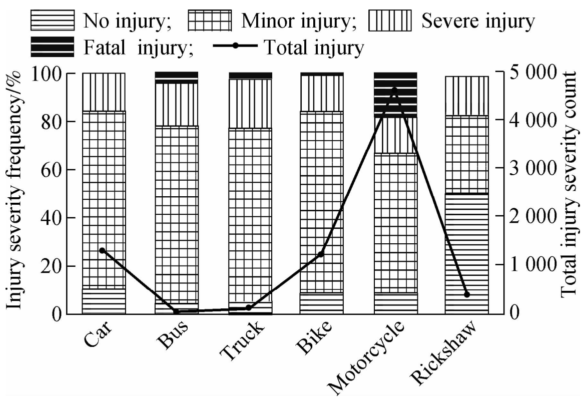

Fig. 1 The severity of crash injury by motorcycles involved in collisions with six different types of vehicles

2 Methodology

Considering random-parameter multinomial logit approaches with heterogeneity in means and variances, the following equation describes a linear function for determining the motorcyclist's injury severity outcome i in crash j[10]:

$$S_{ij} = \boldsymbol{\beta}_i \boldsymbol{X}_{ij} + \varepsilon_{ij} \tag{1}$$

where $\boldsymbol{X}_{ij}$ represents a vector of explanatory variables (rider, roadway, environmental, crash, and temporal attributes); $\boldsymbol{\beta}_i$ denotes the vector of the estimated coefficients; and ε_{ij} is a stochastic error term that accounts for unobserved effects.

A standard multinomial logit model is proposed under the assumption that ε_{ij} follows a generalized extreme value distribution[11]:

$$P_{ij} = \int \frac{e^{\boldsymbol{\beta}_i \boldsymbol{X}_{ij}}}{\sum e^{\boldsymbol{\beta}_i \boldsymbol{X}_{ij}}} f(\boldsymbol{\beta} \mid \boldsymbol{\varphi}) \, d\boldsymbol{\beta} \tag{2}$$

where $f(\boldsymbol{\beta} \mid \boldsymbol{\varphi})$ denotes the probability density function of the random vector $\boldsymbol{\beta}$, while $\boldsymbol{\varphi}$ is a vector of the parameters that influence $f(\boldsymbol{\beta} \mid \boldsymbol{\varphi})$ (mean and variance). $\boldsymbol{\beta}_{ij}$ is a vector of estimable parameters, and it captures the heterogeneity in the mean and variance[12]:

$$\boldsymbol{\beta}_{ij} = \boldsymbol{\beta}_i + \boldsymbol{\delta}_{ij} \boldsymbol{M}_{ij} + \sigma_{ij} e^{\boldsymbol{\omega}_{ij} \boldsymbol{D}_{ij}} \nu_{ij} \tag{3}$$

where $\boldsymbol{M}_{ij}$ denotes a vector of explanatory variable heterogeneity in the mean that influences the motorcyclist's injury severity result i; $\boldsymbol{\delta}_{ij}$ denotes a corresponding vector of the estimated parameter; $\boldsymbol{D}_{ij}$ is a vector of explanatory variables capturing heterogeneity in the standard deviation σ_{ij} with the corresponding parameter vector $\boldsymbol{\omega}_{ij}$; and ν_{ij} is a disturbance term.

To estimate the models in the current work, a simulated maximum likelihood approach with 1 000 Halton draws is proposed[11]. Regarding $f(\boldsymbol{\beta} \mid \boldsymbol{\varphi})$, several density functions, including normal, uniform, lognormal, and triangular distributions, can be devised. However, none of these functions can produce a better statistical fit than a normal distribution, as supported by prior empirical evidence[13-14].

In addition, the marginal effects η of the variables are estimated to account for the change in one unit of a single variable in the random-parameter logit model, which can be represented as

$$\eta_{X_{ij}}^{P_{ij}} = \frac{dP_{ij}}{d\boldsymbol{X}_{ij}} = \frac{d}{d\boldsymbol{X}_{ij}} \int \frac{e^{\boldsymbol{\beta}_i \boldsymbol{X}_{ij}}}{\sum_{\forall I} e^{\boldsymbol{\beta}_i \boldsymbol{X}_{ij}}} f(\boldsymbol{\beta} \mid \boldsymbol{\varphi}) \, d\boldsymbol{\beta} \tag{4}$$

The transferability between various models can be tested as described in Ref. [14]:

$$\chi_g^2 = -2 \left[\mathrm{LL}(\beta_{\mathrm{all}}) - \int_{i=1}^{6} \mathrm{LL}(\beta_{\mathrm{type}i}) \right] \tag{5}$$

where $\mathrm{LL}(\beta_{\mathrm{all}})$ denotes the log-likelihood at convergence for all motorcycle crashes colliding with six types of vehicles, and $\mathrm{LL}(\beta_{\mathrm{type}i})$ denotes the log-likelihood at the convergence of the motorcycle crash model corresponding to type i (car, bus, truck, bike, motorcycle and rickshaw). The degree of freedom is equal to the sum of the statistically significant parameters in the separate model minus the number of statistically significant parameters in the joint model[10]. The χ^2 test results were 265.98 with 59 degrees of freedom, indicating that the null hypothesis that the six types of nonhelmeted motorcycle crash models are the same should be rejected with greater than 99.99% confidence.

Furthermore, to address the non-transferability of the estimated parameters across different disaggregate data, out-of-sample prediction can be used to predict observations from another model using estimated parameters from one model[15-16]. This study employed estimated parameters from one type of nonhelmeted motorcycle crash to predict another type of crash, allowing us to examine the aggregate effects across models. The out-of-sample simulation employed 1 000 Halton draws, similar to the approach used to estimate the probability of injury severity. The average probability differences are computed for out-of-sample prediction, which can be implemented as[15−16]

$$P_j(i) = \frac{1}{N}\sum_{n=1}^{N}\frac{\exp[(\boldsymbol{\beta}_i + \delta_{ij}\boldsymbol{M}_{ij} + \sigma_{ij}e^{\omega_i p_{ij}}\nu_{ij})\boldsymbol{X}_{ij}]}{\sum_{i=1}^{I}\exp[(\boldsymbol{\beta}_i + \delta_{ij}\boldsymbol{M}_{ij} + \sigma_{ij}e^{\omega_i p_{ij}}\nu_{ij})\boldsymbol{X}_{ij}]} \tag{6}$$

where N is the total number of draws used for individual observations. In this study, 1 000 Halton draws were used for out-of-sample prediction to ensure accurate model estimation.

Using parameters estimated from one model to predict observations from another model results in significantly different probabilities (see Tab. 1). For instance, the likelihood of severe injury may be significantly underestimated if the car-nonhelmeted motorcycle model is applied to truck-nonhelmeted motorcycle data. This also demonstrates the unique characteristics of each type of motorcycle crash, which are not interchangeable, consistent with the findings in Refs. [15, 17], in which high degrees of probability differences between respective outcomes were also observed. Nonetheless, compared with a previous study[18], the injury effects of temporal/crash-type changes were found to be relatively high, possibly owing to the disparity between the distributions of male and female nonhelmeted motorcycle crashes. As shown in Fig. 1, the sample size of two-motorcycle nonhelmeted crashes was larger than those of other types, and fatal crashes accounted for 18.5% of two-motorcycle nonhelmeted crashes, compared with less than 5% for other nonhelmeted motorcycle crashes.

Tab. 1 Differences in probabilities among prediction and observed values

Predict model	Car				Bus				Truck			
	NI	MI	SI	FI	NI	MI	SI	FI	NI	MI	SI	FI
Car					0.01	−0.05	0.07	−0.01	0	0	−0.01	0
Bus	−0.01	0	0.01	0					0	0	0	0.01
Truck	0.01	0.01	−0.02	0	0.01	0.01	−0.08	0.06				
Bike	0.02	0.02	−0.04	0	0.01	0.083	−0.04	0.02	0	0.02	−0.03	0.01
Motorcycle	0.01	0.01	−0.02	−0.01	0	0	0.04	−0.04	0	0	−0.03	0.02
Rickshaw	−0.01	0	0.02	−0.01	−0.01	−0.02	0.06	−0.03	−0.01	0.02	−0.03	0.02
Predict model	Bike				Motorcycle				Rickshaw			
	NI	MI	SI	FI	NI	MI	SI	FI	NI	MI	SI	FI
Car	0.01	0.01	−0.02	0	0.01	0	−0.01	0	0	0	0.02	−0.02
Bus	0.02	0.02	−0.05	0	0.01	0.02	−0.02	−0.01	−0.01	−0.01	0.08	−0.05
Truck	0.03	0.03	−0.05	−0.01	0.02	0.01	−0.03	0	−0.01	−0.03	0.03	0.01
Bike					0.02	0.02	−0.04	0	0	0	−0.01	0.02
Motorcycle	0.02	0.01	−0.01	−0.02					−0.01	−0.01	0.07	−0.05
Rickshaw	0.01	0.01	−0.03	0.01	0.01	0	−0.01	0				

Note: NI represents no injury; MI represents minor injury; SI represents severe injury; and FI represents fatal injury.

Overall, the findings on the out-of-sample prediction confirmed a substantial aggregate influence of the non-transferability across different types of nonhelmeted motorcycle crashes.

3 Results and Discussion

Tabs. 2 and 3 illustrate the estimation results for nonhelmeted motorcyclists who collided with different types of vehicles; the results were obtained using random-parameter logit models with heterogeneity in means and variances. The estimation model produced ρ^2 values exceeding 0.400. Several variables significantly influenced the injury severity of nonhelmeted motorcyclists, whereas others were not transferable between the six model types. Owing to the small sample size, only one and two variables were statistically significant in Bus and Truck models, respectively. To further illustrate this non-transferability, the specific marginal effects for each of the six models are presented in Tabs. 4 and 5.

3.1 Rider characteristics

Regarding rider characteristics, all models except the Bus model found the male indicator to be statistically significant. Furthermore, in the Rickshaw model, the male indicator was identified as a random parameter. The marginal effects in Tabs. 4 and 5 revealed that for all five models, male nonhelmeted motorcyclists increased the likelihood of minor injury, with variations in the effects on other injury outcomes. The male indicator increased the likelihood of fatal injury by 0.002 7 and 0.011 2 in the Car and Truck models, respectively, but reduced it by 0.022 2, 0.117 8, and 0.005 4 in the Bike, Motorcycle, and Rickshaw models, respectively. The findings reveal the different crash mechanisms of nonhelmeted motorcyclists colliding with six vehicle types. The mechanisms may be related to the higher speeds of cars[6] and the larger sizes and heavier weights of trucks[19], especially for nonhelmeted motorcyclists.

Tab. 2 Model results of injury severity of nonhelmeted motorcyclists colliding with different types of vehicles (t-Stat. in parentheses)

Variable			Car	Bus	Truck	Bike	Motorcycle	Rickshaw
Constant		NI		−0.724 (−2.65)	−0.690 (−2.57)			
		MI	2.354 (8.12)	2.361 (2.10)	3.164 (5.37)	−5.967 (−9.68)	1.563 (12.09)	−3.223 (−5.11)
		SI	5.293 (9.49)	−4.245 (−3.61)	3.971 (3.84)	1.135 (5.14)	0.373 (2.65)	−2.411 (−5.68)
		FI	−0.476 (−2.47)			−2.656 (−3.45)	1.666 (9.82)	−5.237 (−7.45)
Rider attributes	Male indicator	MI				4.955 (10.20)		
		SI	−5.416 (−10.75)		−2.336 (−2.56)			
		FI					−0.995 (−9.41)	
	Below 20 years indicator	MI				−0.387 (−2.86)		
		SI	0.829 (3.51)					
		FI					−0.730 (−6.53)	
	20-30 years indicator	NI			2.209 (2.97)			
		MI					0.713 (7.77)	
		SI				−0.609 (−2.65)		
	30-40 years indicator	NI						−0.578 (−2.03)
		MI	0.443 (1.98)			0.765 (2.62)	0.419 (3.99)	
	40-50 years indicator	MI					0.329 (2.73)	
		SI	−1.216 (−2.34)					0.713 (2.02)
	Above 50 years indicator	MI					−0.541 (−4.59)	
		FI	0.679 (2.85)			1.112 (2.64)		1.614 (2.74)
Roadway characteristics	Major arterial indicator	NI						−0.456 (−2.04)
		FI	−1.613 (−2.80)					
	Minor arterial indicator	MI	0.437 (2.18)					
		SI				−0.753 (−2.87)		
		FI					−0.179 (−2.82)	
	Lane_2 indicator	NI				−0.815 (−2.23)		
	Lane_4 indicator	MI						4.294 (3.03)
	Speed-70 km/h indicator	NI						1.912 (2.04)
Environmental characteristics	Cloudy indicator	NI				0.691 (2.46)		
Crash characteristics	Distraction indicator	NI					−2.332 (−10.09)	
		MI				2.283 (4.02)		
	Speeding indicator	NI						−0.878 (−2.35)
		MI				3.983 (11.08)		
		SI		2.629 (3.68)			1.095 (2.97)	
		FI	−1.971 (−2.04)					
Temporal characteristics	Weekday indicator	FI	−2.211 (−2.47)				0.209 (2.34)	
	Spring indicator	NI	0.599 (2.59)				0.485 (3.78)	
	Summer indicator	NI						−0.429 (−2.87)
	Autumn indicator	NI	−1.016 (−2.77)					
	Day indicator	NI	0.557 (2.09)				0.332 (2.59)	
		SI				−0.386 (−2.08)		
	Night indicator	FI	2.691 (2.94)				−0.150 (−2.66)	
Random characteristics	Male indicator	MI						1.550 (3.04)
		Std Dev						1.479 (2.52)
	Summer indicator	SI					3.137 (15.74)	
		Std Dev					3.456 (2.81)	
Heterogeneity in the means of random parameters	Male indicator & lane_4 indicator	MI						0.479 (2.52)
	Summer indicator & male indicator	SI					−3.907 (−2.79)	
Heterogeneity in the variances of random parameters	Summer indicator & weekday indicator	SI					−1.035 (−2.13)	

Tab. 3 Goodness-of-fit of the competing model

Model statistics	Car	Bus	Truck	Bike	Motorcycle	Rickshaw
Number of parameters K	16	4	5	14	20	14
Number of observations N	1 281	23	99	1 206	4 602	380
Log-likelihood at zero	−1 775.843	−31.885	−137.243	−1 671.871	−6 379.727	−526.792
p^2	−766.602	−18.806	−76.042	−675.05	−3 712.462	−282.381
Log-likelihood at convergence	0.568	0.41	0.446	0.596	0.418	0.464
Akaike information criterion	1 565.204	45.612	162.084	1 378.1	7 464.924	592.762
Bayesian information criterion	1 647.69	50.154	175.06	1 449.431	7 593.609	647.924

Tab. 4 The marginal effects of determinants in models of nonhelmeted motorcyclists colliding with cars, buses, and trucks

Variable		No injury			Minor injury			Severe injury			Fatal injury		
		Car	Bus	Truck	Car	Bus	Truck	Car	Bus	Truck	Car	Bus	Truck
Rider characteristics	Male indicator	0.053 2		0.020 9	0.307 0		0.264 6	−0.362 9		−0.296 6	0.002 7		0.011 2
	Below 20 years indicator	−0.003 7			−0.020 9			0.024 8			−0.000 2		
	20-30 year indicator			0.095 9			−0.075 0			−0.017 7			−0.003 2
	30-40 year indicator	−0.004 9			0.008 8			−0.003 6			−0.000 3		
	40-50 year indicator	0.000 7			0.004 0			−0.004 8			0.000 1		
	Above 50 years indicator	−0.000 8			−0.004 3			0.005 2			0.000 1		
Roadway characteristics	Major arterial indicator	0.000 2			0.001 8			0.000 3			−0.002 3		
	Minor arterial indicator	−0.005 8			0.011 1			−0.004 8			−0.000 5		
Crash characteristics	Speeding indicator	0.000 7	−0.001 1		0.005 9	−0.002 1		0.000 8	0.005 1		−0.007 4	−0.001 9	
Temporal characteristics	Weekday indicator	0.000 3			0.002 6			0.000 4			−0.003 3		
	Spring indicator	0.012 5			−0.011 0			−0.001 4			−0.000 1		
	Autumn indicator	−0.006 8			0.005 9			0.000 8			0.000 1		
	Day indicator	0.040 8			−0.035 7			−0.005 0			−0.000 1		
	Night indicator	−0.000 8			−0.007 8			−0.001 1			0.009 7		

Furthermore, five age indicators were statistically significant in all six models. Despite showing several inconsistent trends or injury severity levels, the age indicators showed non-transferability across the six models. The marginal effects indicate that people over 50 years old had a positive impact on the likelihood of a fatal injury, whereas other age indicators had a negative impact. This finding is consistent with previous research[20] and is attributable to the higher physiological strength of young groups[16].

3.2 Roadway characteristics

Regarding roadway characteristics, the major arterial indicator tended to reduce the likelihood of no injury in the Rickshaw model. The marginal effects showed that rickshaw-motorcycle crashes at major arterials increased the likelihood of minor, severe, and fatal injuries by 0.031 1, 0.019 0, and 0.001 6, respectively. This finding is attributable to the significant speed differences between the two vehicle types, specifically the lower speed of rickshaws and the higher speed of motorcycles running on major arterials. Moreover, this variable tended to decrease the likelihood of fatal injury in the Car model. The relatively complete safety facilities in major arterials can explain this finding.

In the Car and Bike models, the indicator of minor arterial was negatively related to the likelihood of severe injury. This could be explained by the lower speeds of automobiles and bicycles on minor arterials.

On two-lane roads, the Bike model exhibited an increased likelihood of experiencing minor, severe, and fatal injuries, indicating an unfavorable environment for both Bike and motorcycle riders. In contrast, on four-lane roads, the likelihood of severe and fatal injuries was diminished for the Rickshaw model. This observation is attributable to the presence of a safer riding environment owing to the designated non-motorized lanes and a slower traffic system.

3.3 Environmental characteristics

Regarding environmental characteristics, only cloudy weather reduced the likelihood of minor, severe, and

Tab. 5 The marginal effects of determinants in models of nonhelmeted motorcyclists colliding with bikes, motorcycles, and rickshaws

Variable		No injury			Minor injury			Severe injury			Fatal injury		
		Bike	Motor-cycle	Rick-shaw	Bike	Motor-cycle	Rick-shaw	Bike	Motor-cycle	Rick-shaw	Bike	Motor-cycle	Rick-shaw
Rider characteristics	Male indicator	−0.185 2	0.013 3	−0.175 1	0.515 0	0.086 2	0.248 9	−0.306 6	0.018 2	−0.068 4	−0.022 2	−0.117 8	−0.005 4
	Below 20 indicator	0.004 9	0.002 8		−0.014 3	0.014 7		0.009 9	0.004 3		−0.000 5	−0.021 8	
	20-30 year indicator	0.004 7	−0.011 1		0.010 7	0.051 8		−0.015 9	−0.015 2		0.000 5	−0.025 5	
	30-40 year indicator	−0.003 4	−0.003 3	−0.024 4	0.010 7	0.016 6	0.014 6	−0.006 9	−0.005 0	0.009 2	−0.000 3	−0.008 3	0.000 5
	40-50 year indicator		−0.001 6	−0.011 7		0.007 9	−0.005 0		−0.002 4	0.016 9		−0.004 0	−0.000 2
	Above 50 indicator	−0.000 5	−0.002 2	−0.004 4	−0.001 1	−0.001 4	−0.002 3	−0.001 0	−0.004 2	−0.001 4	0.002 6	0.007 8	0.008 1
Roadway characteristics	Major indicator			−0.051 6			0.031 1			0.019 0			0.001 6
	Minor indicator	0.003 6	0.000 5		0.006 7	0.003 6		−0.010 9	0.000 9		0.000 5	−0.005 0	
	Lane_2 indicator	−0.00 57			0.002 6			0.002 9			0.000 2		
	Lane_4 indicator			−0.099 4			0.099 7			−0.004 9			−0.000 4
	Speed-70 km/h indicator			0.044 6			−0.042 0			−0.002 3			−0.000 2
Environmental characteristics	Cloudy indicator	0.009 0			−0.0055			−0.0033			−0.000 3		
Crash characteristics	Distraction indicator	−0.003 4	−0.009 2		0.009 4	0.005 5		−0.005 6	0.001 5		−0.000 4	0.002 3	
	Speeding indicator	−0.137 6	−0.000 9	−0.185 4	0.384 9	−0.003 9	0.113 6	−0.230 8	0.006 1	0.066 5	−0.016 5	−0.001 2	0.005 3
Temporal characteristics	Weekday indicator		−0.002 3			−0.016 0			−0.004 0			0.022 3	
	Spring indicator		0.008 3			−0.005 3			−0.001 4			−0.001 6	
	Summer indicator		−0.000 1	−0.037 3		−0.007 6	0.022 4		0.017 5	0.013 8		−0.009 9	0.001 1
	Day indicator	0.008 6	0.019 2		0.016 9	−0.012 4		−0.026 5	−0.002 9		0.001 0	−0.004 0	
	Night indicator		0.000 4			0.004 0			0.001 0			−0.005 5	

fatal injuries in the Bike model, possibly because motorcyclists compensate for the risk of slippery roads by riding at reduced speeds and cautiously[21]. However, the issue of self-selectivity discussed in Ref. [22] is another explanation. Self-selected groups of motorcyclists or bicyclists who choose to ride under poor weather conditions are believed to be more dangerous and cause more severe crashes than those who avoid the roadways.

3.4 Crash characteristics

Regarding the collision causes, indicators of distraction and speeding were found to predict the injury severity levels of nonhelmeted motorcycle crashes. The distraction reduced the likelihood of severe and fatal injury in the Bike model while increasing that for the Motorcycle model. Moreover, speeding tended to reduce the likelihood of fatal injury in the Car, Bus, Bike, and Motorcycle models while increasing that for the Rickshaw model, possibly because rickshaws have more vulnerable characteristics.

3.5 Temporal characteristics

Weekday, spring, summer, daytime, and nighttime indicators were significant temporal indicators that affected the severity of injuries in nonhelmeted motorcycle crashes. The effects of weekdays showed non-transferability. Specifically, the Car model exhibited decreased likelihood of fatal injuries on weekdays, while the Motorcycle model exhibited an increased likelihood. This finding is attributable to aggressive riding by middle- and lower-class motorcyclists during their daily commute[20], whereas the number of cars in Pakistan is also significantly lower than that of motorcycles.

The Car and Motorcycle models exhibited decreased injury severity levels during the spring season, showing an increase in the likelihood of no injuries and a decrease in the likelihood of minor, severe, and fatal injuries. The perfect visibility and moderate temperature can provide motorcyclists with ideal riding conditions. However, for the summer season, the Motorcycle and Rickshaw models exhibited an increased likelihood of severe injuries by 0.017 5 and 0.013 8, respectively. The summer monsoon season is characterized by moistened road surfaces, which may increase the risk of severe injuries[6].

Daytime was found to decrease the severe and fatal injury likelihood, whereas nighttime showed differences in the effects on severe and fatal injury likelihood in the Car and Motorcycle models. This finding suggests that motorcyclists may be employing a risk compensation mechanism by reducing their operating speeds and adopting more cautious behaviors during the nighttime, when visibility is poor.

3.6 Heterogeneity in means and variances of random parameters

Two variables were identified as random parameters in the models. In the Motorcycle model, the summer indicator was random and specific to severe injury, with a mean (standard deviation) of 3.137 (3.456). According to the normal distribution, 81.8% of the two-motorcycle crashes that occurred in summer tended to result in severe injuries, whereas the remaining 18.2% of the crashes were less likely to result in severe injuries. Furthermore, the male indicator reduced the mean of the summer indicator by 3.907, whereas the weekday indicator reduced the variances of this random parameter by 1.035. The interactions of these variables revealed that male motorcyclists and weekday periods reduced the likelihood of severe injury in two-motorcycle crashes that occurred during the summer.

In the Rickshaw model, the male indicator was also identified as a random parameter specific to minor injuries, with a mean (standard deviation) of 1.550 (1.479). The normal distribution showed that 85.2% of crashes were more likely to result in minor injuries. In addition, the lane_4 indicator increased the mean of this random parameter by 0.479. This interaction reveals that male nonhelmeted motorcyclists are more likely to sustain minor injuries on four-lane roads. This finding may be explained by the tendency of male nonhelmeted motorcyclists to overspeed and ride carelessly on four-lane roads.

4 Conclusions

1) More restrictive penalties and educational programs should be implemented to prevent distractions and speeding behavior.

2) More educational campaigns and management countermeasures should be organized for motorcyclists over 50 years old, requiring them to wear helmets, obey traffic rules, and refrain from engaging in risky behavior.

3) Alert measures, such as audible reminders and flashing lane lines, should be designed to draw attention to rickshaws on major arterial roads.

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未戴头盔摩托车手与车辆碰撞时伤害严重程度分析

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摘要: 为了研究不同因素对未戴头盔的摩托车手与不同类型车辆碰撞事故严重性程度的影响,基于 2019 年巴基斯坦碰撞事故数据的分析,将事故按照相撞车型划分为汽车、公交车、卡车、自行车、摩托车和人力车 6 种类型,每种类型事故进一步划分为未受伤、轻伤、重伤和死亡 4 个严重程度等级. 从摩托车驾驶员、道路、天气、事故原因和时间 5 个方面选取了 20 个变量,对不同类型事故分别建立了 6 个考虑影响因素异质性的随机参数 Logit 模型. 采用似然比检验和样本外预测方法证实了不同 Logit 模型之间具有不可转移性. 结果表明,所选变量均对事故严重程度具有显著影响,其中摩托车驾驶员的性别、年龄、车道数量、车速对事故严重程度的影响最大. 该研究可以为当地管理者的策略制定提供参考依据,从而降低未戴头盔的摩托车手与其他不同车辆的碰撞事故严重程度.

关键词: 道路安全;伤害严重程度;随机参数 logit 模型;摩托车碰撞;样本外预测
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