Difference Between Male and Female Motorcyclist-Injury Severities: Accommodating Unobserved Heterogeneity in the Data

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Abstract

In Thailand, the frequency of crashes and mortality rates are significantly higher for male motorcyclists than for their female counterparts. This study aims to investigate the effect of various associated risk factors on motorcyclist-injury outcome separated by gender. Using motorcycle-crash data in Thailand from 2016 to 2019, random parameter binary probit with heterogeneity in mean and variances was employed to explore the effects of a wide range of risk characteristics on severity of different motorcyclist gender. In the male model, significant factors are improper overtaking, riding under influence, inner-lane crashes, four-lane crashes, crashes on road with no median, flush median, depressed median, and barrier median, crashes within public area, crashes on wet road, nighttime crashes on lit or unlit road, non-rush hour crashes, evening crashes, weekend crashes, and single-motorcycle crashes. In the female model, significant factors are fatigued rider, three-leg intersection, and midnight/early morning crashes). However, some factors generated contradicting effect between male and female such as hitting a sudden crossing object, U-turn crashes, and hitting passenger car. The split in model estimation between gender is particularly important that could potentially assist policymaker, safety professionals, practitioners, trainer, government agency or highway designer in future planning and serves as guidance for mitigation policies directed at safety improvement for motorcyclist.

Keywords: Motorcyclist, Injury severity, Gender, Random parameter, Unobserved heterogeneity

1. Introduction

Approximately 74% of all road crash deaths in Thailand were attributed to motorcyclists in 2016, and this number is steadily increasing [1]. Motorcyclists have a significantly higher fatality rate in traffic crashes compared to other road users, which is mainly due to the rising number of motorcycle users in low- and middle-income countries and their lack of protection in the event of crashes, as compared to vehicle drivers [1, 2]. Given the disproportionate rise in motorcyclist deaths, it is crucial to investigate the factors that contribute to the severity of injuries sustained by motorcyclists.

Numerous studies have examined the risk factors that have a statistically significant impact on the severity of injuries sustained by motorcyclists. These risk factors include rider behavior and characteristics, roadway conditions, crash characteristics, motorcycle features, and environmental and temporal factors. Interestingly, some of the past research findings have conflicting results, particularly regarding the influence of pillion riders, crashes during the day and night, and the gender of the riders. Specifically, some studies have found that male riders are more likely to suffer from higher injury severity, [2-4], while others have found that they are less likely to do so compared to female riders [5-8]. These conflicting results may be due to differences in data collection periods, data sources, as well as rider nature, which may differ among crash locations, living areas, or countries. Numerous factors can lead to disparities in elements that affect injury severity among male and female motorcyclists. These disparities may arise from the unique physical characteristics of each gender, such as differences in body composition, muscle development, and bone strength, which can influence injury severity [9]. Moreover, variations in riding practices, such as risk-taking and speed, may exist between males and females, with males typically exhibiting more aggressive behavior on the road [10]. The use and fit of safety equipment, motorcycle types and sizes, and the level of training and experience could also vary between genders, potentially impacting the severity of injuries sustained. Furthermore, factors like reaction time, decision-making skills, societal expectations, and cultural norms may contribute to shaping motorcycle riders' behavior and safety attitudes, ultimately influencing injury outcomes. It is crucial to recognize the complex relationships between these factors and their effects on injury severity among male and female riders, as they are not independent and require further investigation and analysis to fully understand their implications [10, 11]. Thus, it can be implied that the role of gender in road crashes is complex; different genders might result in different factors related to motorcycle crash injury severity. Previous studies have shown that a better understanding of gender differences in crash severity can be obtained by estimating separate models for females and males [12-14]. However, the role of gender in determining motorcyclist injury severity, particularly in the context of possible unobserved heterogeneity, has not been studied comprehensively.

Therefore, to address this gap in the literature, this study endeavors to investigate the impact of gender (differences between male and female) and unobserved heterogeneity on the severity of injuries sustained by motorcyclists in Thailand, using motorcycle accident data. The study intends to offer valuable guidance to relevant authorities in developing effective policies that target the correct risk rider group to reduce injury severity based on its findings.

2. Data collection

This study utilized motorcycle-crash data from 2016 to 2019 in Thailand, which was provided by the Highway Information Management System of the DOH. The total number of motorcycle crashes during this period was 13,795, with 32% of them classified as fatal-injury crashes (i.e., resulting in death either at the accident site or at the hospital), while the rest were either injury or no-injury crashes. Additionally, with regards to gender differences, 79% (10,898 cases) of the total number of crashes involved male motorcyclists, while only 21% (2,897 cases) involved female motorcyclists. Within each gender group, as illustrated in Fig. 1, 33% of male motorcyclists sustained fatal injuries, compared to only 28% of female motorcyclists. For this dataset, we previously analyzed the differences in fatality proportions between male and female crashes using the Chi-square test. We determined that their proportions exhibit a significant difference at the p-value 0.01 level. These findings indicate that not only the frequency of crashes, but also the proportion of fatalities, differs significantly between genders.

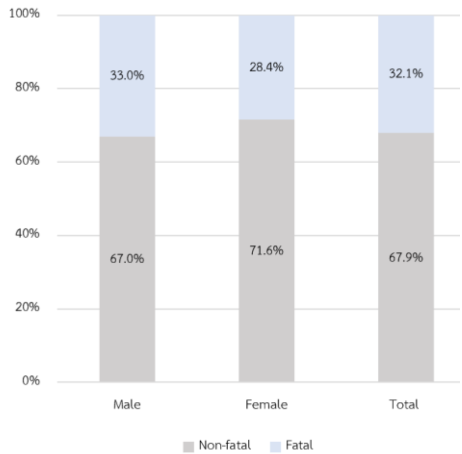

Fig. 1 Male versus female riders' injury severity distribution.

After filtering and cleaning the data, a total of 45 factors were extracted from the original dataset and classified into five groups of explanatory variables, including rider actions and characteristics, roadway characteristics, environmental and temporal characteristics, crash characteristics, and spatial characteristics. Table 1 provides a summary of the significant explanatory variables found in the male and female models, which investigated motorcycle-crash injury severity in Thailand between 2016 and 2019 (All variables are coded as "dummy variables," and their descriptions are given in the table).

Table 1 Descriptive statistics and coding of explanatory variables.

Item	Male (n=10,898)		Female (n=2,897)	
Variable (description)	Freq.	%	Freq.	%
Rider characteristic and action				
Passenger (1 if there are at least one passenger, 0 otherwise)	5220	47.9	1347	46.5
Exceeding speed (1 if rider exceed speed limit, 0 otherwise)	5362	49.2	1393	48.1
Hitting sudden crossing object (1 if rider hit a sudden cross movement, 0 otherwise)	4926	45.2	1208	41.7

Table 1 Descriptive statistics and coding of explanatory variables. (Cont.)

Item	Male (n=10,898)		Female (n=2,897)	
Variable (description)	Freq.	%	Freq.	%
Rider characteristic and action				
Improper overtaking (1 if rider overtaking illegally, 0 otherwise)	1068	9.8	333	11.5
Non-signal (1 if rider doesn't provide turn signal, 0 otherwise)	1090	10	269	9.3
Drunk (1 if rider is under influence of alcohol, 0 otherwise)	1580	14.5	684	23.6
Fatigue (1 if rider falls asleep while riding, 0 otherwise)	1210	11.1	272	9.4
Roadway characteristic				
Inner lane (1 if crash occur on inner traffic lane, 0 otherwise)	2092	19.2	652	22.5
Frontage lane (1 if crash occur on outer traffic lane, 0 otherwise)	2092	19.2	646	22.3
Construction (1 if crash occur on road under maintenance or construction, 0 otherwise)	1515	13.9	423	14.6
4-Lanes (1 if crash occur on 4/more lanes road, 0 otherwise)	5100	46.8	1382	47.7
No median (1 if crash occur on road without median, 0 otherwise)	5242	48.1	1414	48.8
Flush median (1 if crash occur on road with flush median, 0 otherwise)	3531	32.4	872	30.1
Raised median (1 if crash occur on road with raised median, 0 otherwise)	4784	43.9	1223	42.2
Depressed median (1 if crash occur on road with depressed median, 0 otherwise)	4228	38.8	1098	37.9
Barrier median (1 if crash occur on road with barrier median, 0 otherwise)	2768	25.4	855	29.5
Concrete pavement (1 if crash occur on concrete pavement, 0 asphalt pavement)	3531	32.4	936	32.3
Straight road (1 if crash occur on straight road, 0 curve road)	3302	30.3	913	31.5
Road on grade (1 if crash occur on graded road, 0 otherwise)	1776	16.3	492	17
Four-leg intersection (1 if crash occur within 100m from 4-leg intersection, 0 otherwise)	2528	23.2	562	19.4
Three-leg intersection (1 if crash occur within 100m from 3-leg intersection, 0 otherwise)	2942	27	713	24.6
U-turn (1 if crash occur with median opening (U-turn), 0 otherwise)	2921	26.8	742	25.6
Public area (1 if crash occur within public area, 0 otherwise)	1874	17.2	510	17.6
Bridge (1 if crash occur on bridge, 0 otherwise)	1090	10	304	10.5

Table 1 Descriptive statistics and coding of explanatory variables. (Cont.)

Item	Male (n=10,898)		Female (n=2,897)	
Variable (description)	Freq.	%	Freq.	%
Environmental and temporal characteristic				
Wet road (1 if road surface is wet, 0 otherwise)	2441	22.4	603	20.8
Raining (1 if crash occur during fog/raining, 0 otherwise)	2528	23.2	632	21.8
Light (1 if crash occur nighttime with light condition, 0 otherwise)	4425	40.6	1347	46.5
Darkness (1 if crash occur nighttime without light condition, 0 otherwise)	2866	26.3	962	33.2
Holiday (1 if crash occur during holiday period, 0 otherwise)	5416	49.7	1443	49.8
Midnight/early morning	3095	28.4	1008	34.8
Rush hours (1 if crash occur between [07:00-08:59; 16:00-17:59], 0 otherwise)	4926	45.2	1194	41.2
Non-rush hours (1 if crash occur between [09:00-15:59], 0 otherwise)	5340	49	1344	46.4
Evening (1 if crash occur between [18:00-23:59], 0 otherwise)	4555	41.8	1356	46.8
Weekend (1 if crash occur on weekend, 0 weekday)	4871	44.7	1333	46
Crash characteristic and type				
Hitting motorcycle (1 if rider hit other motorcycle, 0 otherwise)	3389	31.1	930	32.1
Hitting passenger car (1 if rider hit passenger car, 0 otherwise)	4882	44.8	1266	43.7
Hitting van or minibus (1 if rider hit van or minibus, 0 otherwise)	5002	45.9	1278	44.1
Hitting truck (1 if rider hit large-truck, 0 otherwise)	2136	19.6	605	20.9
Pedestrian (1 if motorcycle hit pedestrian, 0 otherwise)	3106	28.5	858	29.6
Rear-end crash (1 if crash is rear-end type, 0 otherwise)	5242	48.1	1379	47.6
Sideswipe crash (1 if crash is sideswipe type, 0 otherwise)	4730	43.4	1220	42.1
Single-motorcycle crash (1 if crash is single-vehicle run-off-road type, 0 otherwise)	4218	38.7	1202	41.5
Head-on crash (1 if crash head-on type, 0 otherwise)	2594	23.8	753	26
Spatial characteristic				
Municipal (1 if crash occur within urban area (municipal only), 0 otherwise)	4087	37.5	1055	36.4
Urban (1 if crash occur within urban area, 0 rural area)	4327	39.7	1173	40.5

Note: Freq. = Frequency of “code 1”; % = percentage

3. Methodological development

Among previous approaches utilized in motorcycle crash studies, the random parameter models allowing possible heterogeneity in means and variances are among the most flexible in capturing a greater extent layer of unobserved heterogeneity [12, 15]. Therefore, with respect to the importance of unobserved heterogeneity in the statistical analysis of highway accident data [9], the present study adopted random parameter modeling with heterogeneity in means and variances to empirically investigate the difference in associated factors influencing fatality risk of motorcyclist injury between male and female riders in the context of developing country, Thailand. Prior to the formulation of a random parameter binary probit model that allows for heterogeneity in means and variances of the random parameters, the model starts by defining a function that determine the crash-injury severity as [16]:

$$Y_{in}^* = \beta_i X_{in} + \varepsilon_{in} \quad (1)$$

where Y_{in}^* is a function that determines the probability of motorcyclist-injury severity outcomes i (0 and 1, respectively, for non-fatal and fatal injury) in crash n, β_i is a vector of estimable parameters, X_{in} is a vector of explanatory variable that effect motorcyclist-injury severity level i, and ε_{in} is the disturbance term that assumed to be normally distributed with zero mean and unit variance. For binary response variable case, it can be specified as:

$$\begin{cases} y = 0 \; if \; Y_{in}^* \le 0 \\ y = 1 \; if \; Y_{in}^* > 0 \end{cases} \quad (2)$$

And the probability of outcome y for given X can be estimated as [17]:

$$\begin{cases} P_n(y=0 \mid X) = \Phi(-\beta_i X_i) \\ P_n(y=1 \mid X) = 1 - \Phi(-\beta_i X_i) = \Phi(\beta_i X_i) \end{cases} \quad (3)$$

Where $\Phi(.)$ denotes the standard normal cumulative distribution function. To account for the unobserved heterogeneity in the means and variances of random parameter, β_{in} is treated as a vector of estimable parameters that varies across crashes and can be defined as [18]:

$$\beta_{in} = \beta_i + \Theta_{in} Z_{in} + \sigma_{in} e^{\omega_{in} W_{in}} \nu_{in} \quad (4)$$

where β_i refers to the mean parameter estimate across all crashes, Z_{in} is a vector of the explanatory variable that captures heterogeneity in the mean that influences injury severity i, Θ_{in} represents a vector of estimable parameters, W_{in} refers to a vector of crash-specific variables that captures heterogeneity in the standard deviation σ_{in} with corresponding vector ω_{in}, and disturbance term is denoted by ν_{in}. The model is estimated using the simulated maximum likelihood estimation with 1000 Halton draws to estimate the models. The normal distribution was considered for the function form of parameter density function $f(\beta \mid \varphi)$ that typically provide the best statistical fit in injury severity study [7, 18, 19]. In addition, to ease interpretation of the effect of explanatory variables on the outcome probability, average marginal effects over all crash observations were computed to capture the effect that a one-unit change in any specific explanatory variable has the probability of an injury severity outcome [16]. The econometric and statistical software NLOGIT 6.0 was used for all the model estimations.

4. Likelihood ratio test

In this section, the study conducted a likelihood ratio tests to assess the statistical independence of motorcyclist-injury severity that are significantly different across gender. This test is performed to either accept or reject the null hypothesis, which asserts that the impacts of the parameter estimates for male and female motorcycle crash injury severity are equivalent. The test can be computed as:

$$\chi^2 = -2[LL(\beta_{Total}) - LL(\beta_{Male}) - LL(\beta_{Female})] \quad (5)$$

where $LL(\beta_{Total})$ is the log-likelihood at the convergence of a model using combined data, $LL(\beta_{Male})$ is the log-likelihood at the convergence of a model using male data, and $LL(\beta_{Female})$ is the log-likelihood at the convergence of a model using female data. The test gave χ^2 value of 192.63 distributed with 27 degrees of freedom (equal to the summation of parameters found to be statistically significant in each model minus the number of parameters found to be statistically significant in model using combined data [20]), indicating that the null hypothesis that parameter estimates of the male and female models are the same can be rejected with confidence level greater than 99%.

5. Results and Discussions

Tables 2 and 3 present estimation results using random parameter binary probit allowing possible heterogeneity in means and variances of female and male model, respectively. The explanatory variables that may significantly influence the means (i.e., positive coefficient shifts the mean upward making fatal injury more likely and negative coefficient shifts it downward making fatality less likely) and variances (i.e., positive coefficient makes distribution of random parameter wider and increases their randomness, whereas negative coefficient decreases the variation) were also tested. In terms of goodness of fit, male and female models generated a reasonably good statistical fit with ρ^2 value of 0.137 and 0.177, respectively. All coefficients shown in the tables are statically significant at the 0.1 or lower significant level. In addition to the parameter estimate, average marginal effects of each significant factor were also computed and reported in their respective table.

Table 2 Estimation result for female motorcyclist model.

Explanatory variables	Estimate	Z-value	ME
Rider characteristic and action			
Passenger indicator	0.502***	6.29	0.1183
Standard deviation	1.47***	17.07	
Hitting sudden crossing object indicator	−0.257*	−1.76	−0.0559
Fatigue indicator	0.683**	2.4	0.1782
Roadway characteristic			
Frontage lane indicator	−0.553**	−2.06	−0.1047
Barrier median indicator	−0.584***	−3.01	−0.1107
Concrete pavement indicator	−0.922***	−5.49	−0.1616
Standard deviation	1.109***	8.29	
Road on grade indicator	0.413**	2.07	0.1025
Three-leg intersection indicator	−0.279**	−2.08	−0.0583
U-turn indicator	−0.667***	−3.07	−0.1245
Standard deviation	2.783***	9.47	
Environmental and temporal characteristic			
Wet road indicator	0.510*	1.71	0.1284
Holiday indicator	−0.462***	−4.82	−0.1025
Midnight/early morning indicator	1.073***	8.59	0.2911
Rush hours indicator	0.193**	2.4	0.0442
Weekend indicator	0.288***	2.77	0.0664
Crash characteristic and type			
Hitting motorcycle indicator	−0.255*	−1.85	−0.0539
Hitting passenger car indicator	0.390***	3.49	0.0901
Hitting pick-up truck indicator	0.576***	5.38	0.1352
Hitting van or minibus indicator	0.473***	2.63	0.1177

Table 2 Estimation result for female motorcyclist model. (Cont.)

Explanatory variables	Estimate	Z-value	ME
Crash characteristic and type			
Hitting truck indicator	2.038***	11.99	0.5813
Standard deviation	1.405***	8.83	
Sideswipe crash indicator	−0.247**	−2.08	−0.0535
Head-on crash indicator	0.511***	3.26	0.1288
Spatial characteristic			
Municipal indicator	0.804*	1.7	0.1997
Urban indicator	−1.113**	−2.39	−0.1978
Heterogeneity in mean			
Passenger : Light	0.333**	2.15	
Concrete : Light	0.757***	2.96	
Hitting truck : Light	−0.787***	−2.74	
Heterogeneity in variance			
Passenger : Darkness	0.505***	2.68	
Concrete : Darkness	−1.065***	−2.64	
U-turn : Darkness	5.319***	5.69	
Hitting truck : Darkness	−3.792***	−12.85	

Table 3 Estimation result for male motorcyclist model.

Explanatory variables	Estimate	Z-value	ME
Rider characteristic and action			
Passenger indicator	0.348***	4.51	0.1075
Standard deviation	0.404***	14.69	
Improper overtaking indicator	0.462***	3.48	0.1484
Drunk indicator	−0.838***	−4.31	−0.2081
Standard deviation	0.663***	7.67	
Roadway characteristic			
Inner lane indicator	−0.374***	−5.23	−0.1049
Frontage lane indicator	−0.796***	−8.6	−0.1985
4-Lanes indicator	−0.177**	−2.53	−0.054
Flush median indicator	−0.198	−1.35	−0.0579
Standard deviation	0.425***	8.85	
Depressed median indicator	0.192***	3.71	0.0595
Barrier median indicator	−0.130*	−1.84	−0.0385
Concrete pavement indicator	−0.101**	−2.19	−0.0301
Road on grade indicator	0.192**	2.34	0.0599
U-turn indicator	0.090*	1.71	0.0276
Bridge indicator	0.283**	2.25	0.0892
Environmental and temporal characteristic			
Wet road indicator	0.409***	3.4	0.1309
Light indicator	0.203**	2.31	0.0623
Darkness indicator	0.462***	4.93	0.1488
Holiday indicator	−0.442***	−10.59	−0.1319
Rush hours indicator	−0.604***	−6.91	−0.1684
Non-rush hours indicator	−0.639***	−7.43	−0.1832
Evening indicator	−0.537***	−11.96	−0.1497
Weekend indicator	0.385***	8.66	0.1177

Table 3 Estimation result for male motorcyclist model. (Cont.)

Explanatory variables	Estimate	Z-value	ME
Crash characteristic and type			
Hitting motorcycle indicator	−0.420***	−7.77	−0.1183
Hitting passenger car indicator	−0.081*	−1.96	−0.0244
Hitting pick-up truck indicator	0.140***	3.46	0.0427
Hitting van or minibus indicator	0.228***	3.48	0.0714
Hitting truck indicator	0.832***	16.27	0.2774
Rear-end crash indicator	−0.131***	−2.81	−0.0391
Sideswipe crash indicator	−0.260***	−5.28	−0.0764
Single-motorcycle crash indicator	−0.232***	−2.75	−0.0684
Standard deviation	0.706***	17.3	
Head-on crash indicator	0.307***	4.82	0.0971
Spatial characteristic			
Municipal indicator	0.334***	3.16	0.1032
Urban indicator	−0.514***	−5.02	−0.1446
Heterogeneity in mean			
Passenger : Raised median	−0.177**	−2.5	
Passenger : Straight road	−0.204**	−2.56	
Drunk : Raised median	−0.426**	−2.34	
Flush median : Straight road	0.329**	2.22	
Single-motorcycle crash : Raised median	0.242***	2.95	
Heterogeneity in variance			
Passenger : Midnight/early morning	−0.506*	−1.79	
Drunk : Midnight/early morning	−2.579***	−7.7	
Single-motorcycle crash : Midnight/early morning	−0.283*	−1.91	

5.1 Random parameters and heterogeneity in means and variances

For female motorcyclist model (Table 2), six statically significant random parameters were found, namely, rider with pillion (increase likelihood of fatal injury for 62.71% and decrease it for 37.29% of the observation), crash on concrete pavement (increase likelihood of fatal injury for 21.19% and decrease it for 78.81% of the observation), crash within U-turn area (increase likelihood of fatal injury for 0.14% and decrease it for 99.86% of the observation), rider hitting truck (increase likelihood of fatal injury for 84.87% and decrease it for 15.13% of the observation), rear-end crash (increase likelihood of fatal injury for 42.48% and decrease it for 57.52% of the observation), and sideswipe crash (increase likelihood of fatal injury for 17.63% and decrease it for 82.37% of the observation). For heterogeneity in mean, crash occurring during nighttime on lit road decreases the mean of hitting truck random parameters, thereby making fatal injury less likely to the motorcyclist. On the other hand, fatal injury is more likely as a result of the following: crash during nighttime on lit road increases means of rider with pillion, crash on concrete road and crash within U-turn area random parameter, and crash on flush median road increases the mean of hitting truck and rear-end crash indicator. With respect to heterogeneity in variance, crash during nighttime on unlit road increases variance of rider with pillion and crash with U-turn area (thereby making their distribution wider and increase their randomness) and decreases variance of hitting truck random parameter (thereby decreasing the random parameter's distribution and variation).

For male motorcyclist-injury model, Table 3, seven explanatory variables resulted as significant random parameter: rider with pillion (increase likelihood of fatal injury for 75.07% and decrease it for 24.93% of the observation), rider hitting a sudden object crossing (increase likelihood of fatal injury for 51.46% and decrease it for 48.54% of the observation), rider under influence of alcohol (increase likelihood of fatal injury for 6.34% and decrease it for 93.66% of the observation), crash on inner traffic lane (increase likelihood of fatal injury for 58.42% and decrease it for 41.57% of the observation), crash on flush median road (increase likelihood of fatal injury for 30.44% and decrease it for 69.56% of the observation), crash on concrete pavement road (increase likelihood of fatal injury for 48.17% and decrease it for 51.83% of the observation), and single-motorcycle crash (increase likelihood of fatal injury for 35.85% and decrease it for 64.15% of the observation). Regarding heterogeneity in mean, fatal injury is less likely as a result of crash on raised median road decreasing the mean of rider with pillion and DUI rider random parameters and crash on straight road decreasing the mean of rider with pillion, hitting sudden crossing object and crash on inner-lane random parameters. However, crash on raised median road indicator increases mean of single-motorcycle crash, and crash on straight road increases mean of DUI rider and flush median random parameter; consequently, these results make fatal injury more likely to the motorcyclist. For heterogeneity in variance, crashes occurring between 00:00 AM and 06.59 AM decrease the variance of hitting a sudden object crossing, crash on inner traffic lane, crash on concrete pavement, and single-motorcycle crash indicator, thereby making their distribution smaller and decrease their randomness.

5.2 Rider characteristics

In this category, the model indicates that only two out of six significant variables were found in both the male and female models (Table 5). For both male and female motorcyclists, riders were found to have a higher likelihood of fatal injury when traveling with a pillion rider (with a marginal effect of the random parameter of 0.10624 and 0.11406, respectively). Similar results were found by Quddus et al. [3].

Male riders who hit a sudden crossing object had a higher likelihood of fatal injury, with a marginal effect of the random parameter of 0.01194, while a decrease in the risk of fatal injury was observed for female riders, with a marginal effect of −0.05715. Additionally, male motorcyclists who took improper overtaking were found to have a higher risk of fatal injury, with a marginal effect of 0.15156. These results may be due to male drivers being more likely to exhibit aggressive behavior, such as over-speeding and taking risks, compared to female drivers. These behaviors can further increase the impact of the crash and the level of injury severity [10].

Male riders who rode under the influence of alcohol had a lower risk of fatal injury, but a higher risk of sustaining minor or severe injury, with a marginal effect of the random parameter of −0.22314. Similar findings were also reported in previous studies [2]. On the other hand, fatigued riders were found to increase the risk of fatal injury only among female riders, with a marginal effect of 0.17885, which is consistent with the findings of recent research [19]. These results suggest that male motorcyclists tend to ride their motorcycles after drinking alcohol at entertainment centers, as found in Islam [21], whereas female riders are more likely to be fatigued while riding during nighttime, which is potentially due to weaker physical strength and health compared to the male counterpart.

5.3 Roadway characteristics

The study found that motorcycle crashes occurring on the inner lane (specifically referring to roads with both a frontage lane alongside the main traffic lane relative to roads without a frontage lane) had a higher probability of fatal injury only for the male rider model, with a marginal effect of the random parameter of 0.04759. The results suggest that the majority of inner-lane motorcycle crashes involving male riders increased the risk of fatal injury (58.42% of the observations in Table 3). One possible explanation is that inner-lane traffic serves high volumes of mixed traffic that operate at highway allowable speed limits, which increases the likelihood of high-impact crashes. The remaining 41% of the observations that had a lower likelihood of fatal injury may be attributed to male riders cautiously riding and compensating for the risk of using the inner traffic lane. However, riders involved in crashes on the frontage traffic lane had a lower risk of fatal injury for both male and female models, with a marginal effect of −0.20509 and −0.11169, respectively. This may be due to the low traffic and speed limit on frontage roads, which mainly serve local traffic in community or urban areas.

Male motorcyclists who crashed on a four-lane road had a lower likelihood of fatal injury compared to those who crashed on a two-lane road, with a marginal effect of −0.06219. Compared to highways with a greater number of lanes, crashes on two-lane roads (which are commonly undivided) may be more likely to be head-on crashes for motorcycles, particularly for male riders with risky driving behaviors such as speeding and risky overtaking, which are highly associated with a higher level of injury severity [19].

With regards to the types of medians, crashes on roads with no median, flush median, and barrier median were found to have a lower likelihood of fatal injury for male motorcyclists, with marginal effects of −0.04508 (random parameter), −0.07738, and −0.05397, respectively. However, male motorcyclists who crashed on a road with a depressed median had a higher risk of fatal injury, with a marginal effect of 0.05361. This may be because depressed medians are commonly implemented on intercity roadways in Thailand, which serve mixed and high-speed traffic. In contrast, the findings suggest that barrier medians can provide better safety for motorcycle users, particularly in urban areas, by limiting the option to turn around and redirecting it to a safer location, thus reducing the risk of head-on crashes and other risky overtaking behaviors [19].

For both male and female motorcyclists, being involved in a crash on concrete pavement was found to result in a lower probability of fatal injury, with marginal effects of −0.00732 and −0.12955, respectively. This suggests that motorcyclists may generally operate at lower speeds when riding on concrete roads compared to asphalt pavement roads, possibly due to the noisy and less stable riding experience provided by concrete roads. On the other hand, motorcyclists involved in crashes on graded roads were found to have a higher probability of fatal injury, with marginal effects of 0.05755 and 0.10327 for the male and female models, respectively. This result is consistent with previous studies [22].

Crashes involving motorcycles at three-leg intersections were found to be less likely to result in fatal injuries for female riders (with a marginal effect of −0.05546). This may be because female riders are more careful and approach intersections at a slower speed, reducing their chances of sustaining more severe injuries. On the other hand, male motorcyclists involved in crashes within U-turn areas were found to have a higher probability of fatal injury (with a marginal effect of 0.03265), while the majority of female riders had a lower probability of fatal injury (with a marginal effect of random parameter of -0.27287). This suggests that male motorcyclists are at a greater risk than females when it comes to crashes in U-turn areas, possibly due to their tendency towards aggressive and risky driving behaviors that may result in high-impact collisions with oncoming traffic.

Male motorcyclists who were involved in crashes within public areas (such as markets, shopping malls, parks, etc.) were found to have a lower probability of sustaining fatal injuries, with a marginal effect of −0.04232, which aligns with the findings of Rifaat et al. [2]. On the other hand, crashes on bridges were found to increase the likelihood of fatal injury for both male and female riders, with marginal effects of 0.08529 and 0.14022, respectively. This indicates that regardless of gender, if a motorcycle crash occurs on a bridge, the rider is more likely to die due to the higher chance of falling off the bridge or colliding with a fixed object, such as a handrail, which has been shown to increase the severity of injuries in previous studies [19, 21].

5.4 Environmental and temporal characteristics

Only male motorcyclists were found to have a higher risk of fatal injury when crashing on wet roads or during nighttime on both lit and unlit roads, with a marginal effect of 0.12637, 0.05744, and 0.15259, respectively. These findings were similar to previous studies [22]. Female motorcyclists, on the other hand, were found to be more likely to sustain fatal injury during the midnight to early morning (00:00–06:59) and rush hour (07:00–08:59 and 16:00–17:59), with marginal effects of 0.28343 and 0.04363, respectively. Conversely, male motorcyclists who crashed during rush hours, non-rush hours, and evening time were found to have a lower probability of fatal injury, with marginal effects of −0.18418, −0.20153, and −0.15647, respectively. These results suggest that all motorcyclists, regardless of gender, are at a higher risk of sustaining extremely severe injuries in the event of a collision during nighttime crashes.

The study found that during holiday periods, both male and female motorcyclists had a lower likelihood of sustaining fatal injuries, with a marginal effect of −0.14705 and −0.09560, respectively. Additionally, male motorcyclists who crashed on weekends were found to be more likely to sustain fatal injuries, with a marginal effect of 0.13105. This implies that male riders have a higher incidence of motorcycle crashes during weekends, which are their off-study/off-work days, and may be spending more time on leisure activities.

5.5 Crash characteristics

The study found that when both male and female motorcyclists collided with other motorcycles, they were less likely to sustain fatal injuries, with a marginal effect of −0.13287 and −0.05413, respectively. When male motorcyclists collided with passenger cars, they had a lower risk of fatal injury, with a marginal effect of −0.02805. However, in such collisions, female motorcyclists were more likely to sustain fatal injuries, with a marginal effect of 0.09077. In contrast, when both male and female motorcyclists collided with pick-up trucks, vans/minibuses, and trucks, they were more likely to sustain fatal injuries, as shown by the marginal effects in Tables 3 and 4. These findings align with common sense and are consistent with several previous studies [2, 4, 6, 7, 22].

Regarding crash types, male motorcyclists involved in rear-end and sideswipe crash were less likely to sustain fatal injury in crash (with marginal effect of −0.04827 and −0.09189, respectively). In addition, in female model, majority of the observation were also found to be less likely to involve in fatal crash (with marginal effect of the random parameters of −0.02007 and -0.03452, respectively). Male riders involved in single-vehicle crashes were found to have lower probability in majority of the observation (with marginal effect of the random parameter of −0.08533). Lastly, for both male and female motorcyclist model, riders involved in head-on crash were more likely to sustain fatality in crash with marginal effect of 0.10484 and 0.13053, respectively. Again, this finding is reasonable and supported by the previous work [19].

5.6 Spatial characteristics

The study found that both male and female motorcyclists have a higher chance of sustaining a fatal injury if they are involved in a crash in the municipal area (provincial urban area) with a marginal effect of 0.11402 and 0.21188, respectively. However, in both male and female models, crashes occurring on urban roads (including Bangkok, the capital city of Thailand) are less likely to be fatal compared to rural road crashes, with marginal effects of −0.15807 and −0.20634, respectively. This indicates that rural roads are generally more dangerous for motorcyclists than urban roads, and crashes in provincial urban areas are more dangerous than those that occur in Bangkok City. This result is consistent with the findings of Kashani et al. [23]. One possible explanation for this is the longer distance and/or lower quality of medical services provided in rural medical centers compared to urban areas or provincial urban areas compared to Bangkok City.

6. Summary and conclusion

This study used motorcycle-crash data from Thailand between 2016 and 2019 to investigate the impact of various risk factors on the severity of injuries sustained by male and female motorcyclists. The study focused on factors such as rider behavior, road conditions, environmental and temporal factors, crash characteristics, and spatial factors. To analyze the data, the researchers used a random parameter binary probit model with heterogeneity in means and variances, which allowed them to examine how crash-level attributes affected the distribution of random parameters. The study considered two distinct injury outcomes: non-fatal and fatal injuries. The results of the transferability tests showed that there were statistically significant differences in the risk factors associated with male and female motorcyclists.

The gender-based model estimation in this study is significant and can be useful for policymakers in developing safety measures for motorcyclists. For instance, the significance of gender-based model estimation in this study can be valuable for policymakers when devising safety measures for motorcyclists. For example, the findings on rider characteristics demonstrated that the crash injury severity of male riders was associated with their risky behavior (such as drinking and improper overtaking), while this was not observed in female riders. Consequently, authorities should concentrate on mitigating risks based on rider gender by implementing road safety education campaigns. Moreover, riding at night with or without lights has been linked to increased injury severity for male riders, but not for female riders. As highlighted, this study revealed distinct factors related to motorcycle injury severity for each gender. Therefore, relevant organizations can establish policies or strategies to reduce road violence based on the factors identified in this study, taking gender into account.

From a spatial characteristic, as the frequency and mortality rate of motorcycle accidents are higher in rural areas of Thailand, policymakers should educate rural communities about the importance of wearing helmets to increase helmet use among motorcyclists. Additionally, policymakers should investigate the appropriateness of the location of intercity medical treatment centers and consider installing protective guardrails on bridge sections to prevent riders from falling off. While there may be cost constraints, special guardrails with safety devices for motorcyclists should be installed on the lower part of traditional guardrails at roadway level. In order to reduce the risk of collisions between motorcycles and large vehicles such as trucks, pickup cars, and vans, authorities should control the driving speed, cover all types of vehicles, or consider providing motorcycle exclusive lanes [19].

In terms of methodological implications, for traditional models, non-significant fixed variables would typically be disregarded and removed. However, unobserved heterogeneity can address this bias, as it represents variables that do not directly influence dependent variables but may have an indirect effect on them (i.e., it affects the random parameters of the model and thereby increases model complexity). The findings of this study demonstrate that this interpretation bias can be rectified by incorporating unobserved heterogeneity in a comprehensive statistical analysis. Research that has not concentrated on unobserved characteristics might have overlooked certain crucial insights.

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