6-21-2016

The Effects of Age and Gender on Pedestrian Traffic Injuries: A Random Parameters and Latent Class Analysis

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The Effects of Age and Gender on Pedestrian Traffic Injuries:

A Random Parameters and Latent Class Analysis

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Civil Engineering
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

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Date of Approval:
May 5, 2016

Keywords: Pedestrian Injury Severities, Mixed Logit Model, Latent Class Logit Model

DEDICATION

I dedicate this thesis to my family especially my parents Masrianto and Patriasari whose affection, love, encouragement, prays of days of nights make me able to get better, better, better, and better education in my life. I hope this achievement will complete the dream that you had for me many years ago.

ACKNOWLEDGMENTS

First I would like to thank Allah SWT, the Almighty God, for providing me this opportunity and granting me the capability to accomplish this thesis. This thesis paper would not have been possible without the help of so many people in so many ways.

I gratefully acknowledge the support and guidance from Dr. Mannering, my major professor. Without his thoughtful encouragement and careful supervision, this thesis would never have taken shape. I am also grateful to Dr. Lin and Dr. Wang for being my committee members who gave me several ideas in this research.

My thanks also go out to my family (Bapak, Mami, Mas Tomi, Mbak Andin, Kanaia, Anandito, and Anditi) in Semarang and Jakarta for their supports from Indonesia. I also thank to my patient girlfriend, Jihan for her help in waking me up every morning to work on my thesis paper.

I would also like to thank Nikhil for checking my grammar in this thesis paper. Without his help, I could not submit my paper quicker.

I am thankful to my Indonesian friends in Tampa (Suyan, Novi, Evelyn, Jessicca, Edo, Rendy, Mega, Munif, Sylvia, and Septi) for giving me a motivation to come to USF library to finish my thesis paper.

Finally, I would also to thank all faculty and staff in Department of Civil and Environmental Engineering, College of Engineering, University of South Florida for their kind help and co-operation throughout my study period.

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ABSTRACT

Pedestrians are vulnerable road users because they do not have any protection while they walk. They are unlike cyclists and motorcyclists who often have at least helmet protection and sometimes additional body protection (in the case of motorcyclists with body-armored jackets and pants). In the US, pedestrian fatalities are increasing and becoming an ever larger proportion of overall roadway fatalities (NHTSA, 2016), thus underscoring the need to study factors that influence pedestrian-injury severity and potentially develop appropriate countermeasures. One of the critical elements in the study of pedestrian-injury severities is to understand how injuries vary across age and gender – two elements that have been shown to be critical injury determinants in past research. In the current research effort, 4829 police-reported pedestrian crashes from Chicago in 2011 and 2012 are used to estimate multinomial logit, mixed logit, and latent class logit models to study the effects of age and gender on resulting injury severities in pedestrian crashes. The results from these model estimations show that the injury severity level for older males, younger males, older females, and younger females are statistically different. Moreover, the overall findings also show that older males and older females are more likely to have higher injury-severity levels in many instances (if a crash occurs on city streets, state maintained urban roads, the primary cause of the crash is failing to yield right-of way, pedestrian entering/ leaving/ crossing is not at intersection, road surface condition is dry, and road functional class is a local road or street). The findings suggest that well-designed and well-placed crosswalks, small islands in two-way streets,

narrow streets, clear road signs, provisions for resting places, and wide, flat sidewalks all have the potential to result in lower pedestrian-injury severities across age/gender combinations.

CHAPTER 1: INTRODUCTION

Different people have different preferences and limitations when it comes to travel. Some would prefer to (or are limited to) travelling by motorbikes, public transit, single-occupant cars, multiple-occupant cars, etc. However, no matter what the preferences/limitations are, the nature of travel ensures that individuals will be pedestrians at some point. Pedestrians are a well-known class of vulnerable road users. In the United States, there were 4,884 pedestrian fatalities and 65,000 pedestrian injuries (FARS, 2016) and pedestrian fatalities have increased 1.54% since 2013 (NHTSA, 2016). Among many other factors, this increase may be a reflection of safer cars that may encourage people to drive less cautiously, the growing problem of texting and cell-phone use while driving, and so on (Winston et al., 2006). Moreover, as shown in National Highway Traffic Safety Administration (NHTSA) and the Fatal Accident Reporting System (FARS), pedestrian fatalities in 2012, 2013, and 2014 were 14.26%, 14.47%, and 14.94% of the total traffic fatalities in the US, respectively. These increasing traffic-fatality proportions underscore the importance of studying pedestrian-injury severities in order to understand influencing factors and develop effective countermeasures.

There has been a substantial body of work previously undertaken on pedestrian-injury severities. These have included studies that have dealt with the effects of vehicle bumper height (Matsui, 2005), the effects of economic recessions (Behnood and Mannering, 2015), and the effects of age (Kim et al., 2008). However, the combined effects of age and gender on resulting injury severities for pedestrians have not been thoroughly investigated to date.

Based on the findings of previous research, age has been shown to be a strong determinant of injury severity. Older pedestrians tend to have higher injury severity levels relative to other age groups (Fontaine and Gourlet, 1997; Sklar et al., 1989). Moreover, older pedestrians are more likely to be crash-involved relative to their younger counterparts (Fontaine and Gourlet, 1997). Tournier et al. (2015) argue that this is likely the result of a decrease in walking skills, walking speeds, balance, vision, and hearing skills compared to younger people. The effects of age are well documented in the literature with stride lengths, standing widths, and posture all changing for the worse as age increases (Tournier et al., 2015). On the other extreme, younger pedestrians, boys and girls 5 to 9 years old, have also been shown to be at high risk of being involved in pedestrian accidents, which is likely the effect of inexperience and poor judgment (Fontaine and Gourlet, 1997).

Although age is likely to influence resulting pedestrian injury severities, gender is another factor that might come into play. Fontaine, and Gourlet (1997) found that females were less likely to undertake high-risk behaviors so that the probability of females having high injury-severities tended to be lower than their male counterparts. This reflects the findings from NHTSA and FARS that show that male pedestrians had a greater risk of being involved in pedestrian crashes with 69% of total pedestrian fatalities being males (NHTSA and FARS, 2016). In addition, there is a physiological difference between the genders that will also play a role in injury outcomes.

In the current study, the effect of gender and age on pedestrian injury-severity levels will be analyzed by determining statistically different sub-populations in the pedestrian-injury data. Specifically, separate models based on age and gender will be estimated which will enable a full assessment of differences across age and gender categories. Moreover, to capture unobserved heterogeneity in the data, random parameters and latent class models will be estimated. The results of this paper will help establish the relationships between age and gender on resulting injury-severity levels in pedestrian crashes and it will provide some new insights to improve pedestrian safety.

CHAPTER 2: METHODOLOGY

2.1 Statistical Models

There has been extensive research undertaken on the study of injury severities in crashes (see Savolainen et al., 2011 and Mannering and Bhat, 2014) and many types of statistical models have been used to analyze crash-related injury severities (see Savolainen et al., 2011 and Mannering and Bhat, 2014). The most commonly used modeling approaches are ordered probit or logit models, multinomial logit models, nested logit models, mixed logit models, and latent class logit models. Due to the ordinal nature of injury severities (such as no injury, minor injury, severe injury), ordered probit or logit models may be appropriate (Zhu and Srinivasan, 2011; Islam and Hernandez, 2013). However, this model has a limitation in that it does not have the flexibility to explicitly capture interior category probabilities (Washington et al., 2011; Savolainen and Mannering, 2007). For example, if an airbag has deployed because of a collision, the expectation of having severe injury will decrease and the expectation of having no injury will increase. In reality, because of the airbag deployment, the likelihood of having minor injuries may increase. In this case, it is not possible to capture the probability of having minor injuries (one of the interior category probabilities) using standard ordered probit or logit models. Because of this limitation, traditional ordered probit and ordered logit models may not appropriate to model the effects of age and gender on resulting injury severities in pedestrian crashes.

Multinomial logit models are more flexible in capturing the probabilities of injury severities than their ordered probit or logit models counterparts (Malyshkina and Mannering, 2008;

Jones, Gurupackiam and Walsh, 2013; Shaheed and Gkritza, 2014; Islam and Mannering, 2006). However, simple multinomial logit models have the Independence of Irrelevant Alternatives (IIA) problem which can lead to erroneous estimation results (Washington et al., 2011). This problem can be addressed by nested logit models that capture the unobserved effects shared by some (but not all) of the possible injury severity outcomes. However, nested logit models cannot capture unobserved heterogeneity in the data.[1] In this case, mixed logit models and latent class logit models can address this issue by capturing the unobserved heterogeneity in the data (Morgan and Mannering, 2011; Behnood and Mannering, 2015; Mannering et al., 2016). These two modeling approaches are the most widely applied for studying the injury severity-related crashes. In the forthcoming analysis multinomial logit, mixed logit, and latent class logit models will be estimated to model the effects of age and gender on resulting injury severity in the case of pedestrian crashes.

2.1.1 Multinomial Logit Model

The multinomial logit modeling approach is described in detail in references such as Train (2009) and Washington et al. (2011). The multinomial logit model for determining each injury severity outcome can be expressed first by defining an injury-severity function:

$$U_{in} = \beta_i X_{in} + \varepsilon_{in} \tag{1}$$

where U_{in} represents the severity function for injury outcome *i* of the pedestrian crashes in crash *n*, β_i represents a vector of estimable parameters for injury severity outcome i, X_{in} represents a vector of observable characteristics that affect injury severity level *i* in crash *n,* and ε_{in} represents an error term or disturbance term for injury severity outcome *i* in crash n.

[1] An example of unobserved heterogeneity is the effects of fuel price change on how much mileage that people will drive. The expectation of this is people with high income might not be sensitive in the fuel price change. However, there might be other unobserved factors that affect the sensitivity of people in driving such as a vehicle that is wasteful in fuel consumption.

If the error term is assumed to follow an extreme value distribution, a standard multinomial logit model formulation results as (Washington et al., 2011):

$$P_n(i) = \frac{EXP\ [\beta_i X_{in}]}{\sum_{\forall I} EXP\ [\beta_i X_{in}]} \tag{2}$$

where $P_n(i)$ represents the probability of crash *n* that has injury severity *i*.

To interpret the results of the model estimation, elasticity is one of the techniques that can be used. The elasticity can be calculated for variable x_{ki} in each crash *n* as, with subscripting *n* removed for convenience, (Washington et al., 2011; Islam and Mannering, 2006):

$$E_{x_{ki}}^{P(i)} = \frac{\partial P(i)}{\partial x_{ki}} * \frac{x_{ki}}{P(i)} \tag{3}$$

where $P_n(i)$ represents the probability of injury severity for pedestrian outcome *i* and x_{ki} represents the value for variable *k* for outcome *i*. By using the two previous equations, the elasticity equation becomes:

$$E_{x_{ki}}^{P(i)} = [1 - P(i)]\beta_{ki} X_{ki} \tag{4}$$

where β_{ki} represents the parameter estimate for variable *ki.* This elasticity can be interpreted as a percent change that a 1% change in X_{ki} that will have on the probability of pedestrian injury severity *i*.

2.1.2 Mixed Logit Model

The mixed logit model is similar to the multinomial logit model but accounts for possible unobserved heterogeneity in the data by allowing parameters to have variations across observations (see Mannering et al., 2016, for a complete discussion of heterogeneity models). For determining the injury severity outcome, consider equations (1) and (2), and a mixing distribution so that (see Washington et al. 2011):

$$P_n^m(i) = \int_x \frac{EXP\ [\beta_i X_{in}]}{\sum_I EXP\ [\beta_i X_{in}]} f(\beta|\varphi) d\beta \tag{5}$$

where $P_n^m(i)$ represents an average of probability of a regular multinomial logit model $P_n(i)$ determined by function $f(\beta|\varphi)$. This $f(\beta|\varphi)$ represents the function that shows the density of β with φ which is the variance of the density function (Train, 2009; Washington et al. 2011; Morgan and Mannering, 2011).

For estimating a mixed logit model, simulated maximum likelihood approaches are applied. An efficient way to calculate the probability for this model is Halton sequence approach (Bhat, 2003). Anastasopoulos and Mannering (2009) found that 200 Halton draws were sufficient for accurate parameter estimation. This Halton sequence approach draws the value of β_i from $f(\beta|\varphi)$ so that accurate model estimation will be obtained (Washington et al., 2011; Morgan and Mannering, 2006; Behnood and Mannering, 2015).

2.1.3 Latent Class Logit Model

This model is a special form of the mixed logit model and has the same distributional assumptions (Behnood, and Mannering, 2015; Mannering et al., 2016). This latent class model allows the pedestrian injury severity to have *C* different classes so that each of classes will have their own parameters with the probability as (Behnood et al., 2014):

$$P_n(c) = \frac{EXP\ (\alpha_c Z_n)}{\sum_{\forall C} EXP(\alpha_c Z_n)} \tag{6}$$

where Z_n represents a vector that shows the probabilities of *c* for crash *n*, *C* is the possible classes *c*, and α_c represents the estimable parameters. The probability of pedestrian *n* having injury severity *i* is:

$$P_n(i) = \sum_{\forall C} P_n(c) * P_n(i|c) \tag{7}$$

where, $P_n(i|c)$ represents the probability of pedestrians to have injury severity level i for crash n in class c. Based on equations (6) and (7), the latent class logit model for class c will be:

$$P_n(i|c) = \frac{EXP\ (\beta_{ic} X_{in})}{\sum_{\forall I} EXP(\beta_{ic} X_{in})} \tag{8}$$

where, I represents the possibility of injury severity level that pedestrians will have for crash n. Finally, the latent class logit model can be estimated with maximum likelihood procedures (Greene and Hensher, 2003).

2.2 Log-Likelihood Ratio Test

In this study, to test whether or not the injury severity of pedestrian models is significantly different across age and genders, log-likelihood ratio tests are applied (Washington et al., 2011). First, log-likelihood for all groups (full-sample) models is estimated. Second, log-likelihood for each gender and age have to be estimated. Finally, log-likelihood ratio test can be calculated by using this log-likelihood ratio test formula:

$$X^2 = -2\left[LL(\beta_{Tot}) - \sum_{k=1}^{K} LL(\beta_k)\right] \tag{9}$$

where $LL(\beta_{Tot})$ is the log-likelihood at convergence for the full sample (all age and gender groups), $LL(\beta_k)$ is the log-likelihood at convergence for the model using subset k data (gender and age) and K is the total subsets that are going to be used. The X^2 statistic is chi-squared distributed with the degrees of freedom equal to the sum of the number of parameters in the subset models minus the number of parameters in the full-sample model. The result of the χ^2 test shows whether or not the model for subset data is significantly different than the model for the full-sample data.

To find the difference between specific gender and age groups, a second log-likelihood ratio test is applied. The test statistic is:

$$X^2 = -2\ [LL(\beta_{AB}) - LL(\beta_A)] \tag{10}$$

where β_{AB} is the log-likelihood at convergence for a model using data from AB group on subset data from A group and $LL(\beta_A)$ is the log-likelihood at convergence for a model using data from A group. The X^2 statistic is again χ^2 distributed and it shows whether or not the subset models have parameters that are statistically different. The combination of these two log-likelihood ratio tests can show potential differences of various gender and age combinations with regard to pedestrian injury severity.

CHAPTER 3: EMPIRICAL SETTING, THE CALCULATION OF LOG-LIKELIHOOD RATIO TESTS AND MODEL ESTIMATION RESULTS

A number of previous studies have looked at age categories for males and females with regard to injury-severity outcomes. For example, Islam and Mannering (2006) determined significant age categories from 16 to 24 years, 25 to 64 years, and from 65 years or more. Morgan and Mannering (2011) found statistical differences between males and females and those under 45 years old and those 45 years old and older. In other work, Hill and Boyle (2006) determined significant age categories for females with age categories were 16 to 34 years, 35 to 54 years, 55 to 74 years, and 75 years and older.

These previous studies have largely focused on the injury severities of vehicle occupants. However, the age thresholds are likely to be different for pedestrians because of their direct exposure to crash forces and resulting energy dissipation. After extensive empirical investigation, the age categories determined to provide the best statistical fit in the current study were to consider male and females under 50 years old and 50 years old and older. This age split is supported by the literature relating to the effects of age on muscle strength, bone density, and muscle mass. Studies have shown that muscle strength, bone density, and muscle mass will reach their highest levels between 25 to 35 years of age and it will decrease by 12-14% per decade after 50 years of age (Asmussen and Nielsen, 1962; Buchner et al., 1997; Lynch et al., 1999; Metter et al., 1997). It is the age-range of this deterioration that is found to have the most significant effect on pedestrian-injury outcomes.

3.1 Empirical Setting

A total 4829 observations of pedestrian crash severities are available for use in this study. These data were from police- reported pedestrian crashes that were collected in Chicago, Illinois. The data in this study was a subset of the data from a paper written by Behnood and Mannering (2015). In their study, crash data from 2005 until 2012 were used to evaluate the effects of economic recessions on pedestrian-injury crashes. However, the current study only used the data from 2011 to 2012 (the most recent years available) to analyze the effects of age and gender on resulting injury severity in pedestrian crashes. The crash data that were used in this study contained standard information on traffic crashes such as time, location, severity of crashes, driver characteristics, crash attributes (major cause of crash), environmental conditions, roadway conditions, and roadway classification. The data for each crash record in this study included 22 explanatory variables that can be seen in Table 1. Moreover, the dependent variable for each models was the injury severity level (categorized by three groups: no injury, minor injury, and severe injury[2]) for pedestrians.

Pedestrian injury frequencies for all models and the means and standard deviations of all variables included in the forthcoming model estimations are presented in Table 2 and Table 3.

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[2] Savolainen et al. (2011) found that most of minor crashes in all crash databases is usually under- reported. It can lead to an estimation errors or estimation biases. Moreover, Ye and Lord in 2011 explored the underreporting of crashes data on several models.

Table 1 Variables available to estimate the effects of age and gender on pedestrian traffic injuries

Variable no.	Variable description
1	Crash severity: 1 if the crash resulted in the severity level specified in row, 0 otherwise
2	Crash severity: 1 if no injury, 2 if minor injury, 3 if severe injury
3	Age of pedestrian in years
4	Gender: 1 if male, 2 if female
5	Pedestrian action: 3 if turning left; 4 of turning right; 20 if enter from drive/alley; 50 if no action; 51 if crossing – with signal; 52 if crossing – against signal Entering/Leaving/Crossing: 53 if school Bus (within 50 ft.); 54 if parked vehicle; 55 if not at intersection Walking: 56 if with traffic; 57 if against traffic; 58 if to/from disabled vehicle Other: 59 if waiting for school bus; 60 if playing/working on vehicle; 61 if playing in roadway; 62 if standing in roadway; 63 if working in roadway; 64 if other action; 65 if intoxicated pedestrian; 99 if unknown/NA
6	Pedestrian location: 1 if in roadway; 2 if in crosswalk; 3 if not in available crosswalk; 4 if crosswalk not available; 5 if driveway access; 6 if not in roadway; 7 if in bikeway; 9 if not known
7	Pedestrian visibility: 1 if no contrasting clothing; 2 if contrasting clothing; 3 if reflective material; 4 if other light source used
8	Day of week: 1 if Monday, 2 if Tuesday, 3 if Wednesday, 4 if Thursday, 5 if Friday, 6 if Saturday, 7 if Sunday
9	Class of roadway: 1 if controlled rural; 5 if controlled urban; 6 if state numbered urban; 7 if unmarked highway urban; 8 if city streets urban; 9 if toll roads urban
10	National highway system: 1 if yes; 2 if no
11	Traffic control device: 1 if no controls, 2 if stop sign/flasher, 3 if traffic signal; 4 if yield; 5 if police/flagman, 6 if railroad crossing gate, 7 if other RR crossing, 8 if school zone, 9 if no passing, 10 if other regulatory sign, 11 if other warning sign, 12 if lane use marking, 13 if other
12	Road surface condition: 1 if dry, 2 if wet, 3 if snow or slush, 4 if ice, 5 if sand, mud, dirt, 9 if not known
13	Light condition: 1 if daylight, 2 if dawn, 3 if dusk, 4 if darkness, 5 if darkness, lighted road
14	Weather: 1 if clear, 2 if rain, 3 if snow, 4 if fog/smoke/haze, 5 if sleet/hail, 6 if severe cross wind

Table 1 (continued)

15	Primary cause: 1 if exceeding authorized speed limit, 2 if failing to yield right-of way, 3 if following too closely, 4 if improper overtaking/passing, 5 if driving wrong side/wrong way, 6 if improper turning, 7 if turning right on red, 8 if under the influence of alcohol/drugs, 10 if equipment/vehicle condition, 11 if weather, 12 if road/surface/marking defects, 13 if road construction/maintenance, 14 if vision obscured, 15 if driving skills/knowledge, 17 if physical condition of driver, 18 if unable to determine, 19 if had been drinking (use when arrest is not made), 20 if improper lane usage, 22 if disregarding yield sign, 23 if disregarding stop sign, 24 if disregarding other traffic signs, 25 if disregarding traffic signals, 26 if disregarding road markings, 27 if exceeding safe speed for conditions, 28 if failing to reduce speed to avoid crash, 29 if passing stopped school bus, 30 if improper backing, 32 if evasive action due to animal, object, nonmotorist, 40 if distraction from outside vehicle, 41 if distraction from inside vehicle, 42 if cell phone distraction, 43 if non-cell phone electronics, 50 if operating vehicle in erratic, reckless, careless, negligent or aggressive manner, 99 if not applicable
16	Traffic control device condition: 1 if no controls, 2 if not functioning, 3 if functioning improperly, 4 if functioning properly, 5 if worn reflective material, 6 if missing
17	Intersection related: 1 if yes, 2 if no
18	Hit and run crash: 1 if yes, 2 if no
19	Roadway alignment: 1 if straight and level, 2 if straight on grade, 3 if straight on hillcrest, 4 if curve, level, 5 if curve on grade, 6 if curve on hillcrest
20	Roadway description: 1 if not divided, 2 if divided, no median barrier, 3 if divided w/median barrier, 4 if center turn lane, 5 if one-way or ramp, 6 if alley or driveway, 7 if parking lot
21	Roadway functional class: 10 if interstate, 30 if other principal arterial, 70 if minor arterial (urban), 80 if collector (urban), 90 if local road or street (urban)
22	Work zone: 1 if yes, 2 if no

Table 2 Pedestrian injury frequency and percentage distribution (numbers in the parenthesis are the percentage of total crashes)

Population	No injury frequency	Minor injury frequency	Severe injury frequency	Total
Younger male	580 (32.69)	924 (52.10)	269 (15.15)	1773
Younger female	582 (35.64)	837 (51.27)	213 (13.03)	1632
Older male	239 (33.85)	336 (47.61)	130 (18.39)	705
Older female	219 (33.69)	309 (47.56)	121 (18.59)	649

Table 3 The means and standard deviations of all variables included in the forthcoming model estimations

Variable description	Younger male		Younger female		Older male		Older female	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Class of roadway								
State numbered urban road (1 if collision on state numbered urban road segment; 0 otherwise)	0.08	0.26	0.08	0.27	0.10	0.31	0.08	0.08
City streets urban road (1 if collision on city streets urban road segment; 0 otherwise)	0.92	0.28	0.91	0.28	0.88	0.32	0.92	0.92
Pedesterian action								
Crossing – against signal (1if pedestrian action is crossing – against signal, 0 otherwise)	0.09	0.28	0.08	0.27	0.11	0.31	0.07	0.26
Crossing – with signal (1if pedestrian action is crossing – with signal, 0 otherwise)	0.20	0.40	0.32	0.47	0.22	0.42	0.39	0.49
Other (1 if pedestrian action is other; 0 otherwise)	0.18	0.38	0.16	0.36	0.15	0.35	0.14	0.34
Not at intersection (1if pedestrian entering/leaving/crossing is not at intersection, 0 otherwise)	0.05	0.23	0.04	0.21	0.07	0.25	0.06	0.06
Walking with traffic (1 if pedestrian is walking with traffic; 0 otherwise)	0.07	0.25	0.07	0.26	0.05	0.22	0.50	0.23
Walking against traffic (1 if pedestrian is walking against traffic; 0 otherwise)	0.07	0.35	0.06	0.23	0.06	0.24	0.06	0.23
Intoxicated pedestrian (1 if pedestrian is an intoxicated pedestrian; 0 otherwise)	0.03	0.18	0.01	0.10	0.04	0.19	0.01	0.11
Stand (1 if pedestrian is standing in roadway; 0 otherwise)	0.06	0.23	0.05	0.22	0.07	0.25	0.04	0.19
Pedestrian location								

Table 3 (Continued)

In roadway (1 if pedestrian location is in roadway; 0 otherwise)	0.50	0.50	0.36	0.48	0.46	0.50	0.31	0.46
In crosswalk (1if pedestrian location is in crosswalk, 0 otherwise)	0.30	0.46	0.47	0.50	0.33	0.47	0.55	0.50
Crosswalk not available (1 if pedestrian location is not available crosswalk; 0 otherwise)	0.01	0.12	0.01	0.12	0.01	0.11	0.03	0.16
Traffic control device								
No controls (1 if there is no traffic control device, 0 otherwise)	0.55	0.50	0.39	0.49	0.46	0.50	0.35	0.48
Traffic signal (1 if traffic control device is traffic signal; 0 otherwise)	0.32	0.47	0.41	0.49	0.39	0.49	0.45	0.50
Road surface condition								
Dry (1 if road surface condition is dry; 0 otherwise)	0.76	0.43	0.76	0.43	0.78	0.41	0.77	0.42
Light condition								
Darkness and lighted (1 if darkness and lighted roadway; 0 otherwise)	0.30	0.46	0.27	0.45	0.24	0.43	0.04	0.20
Dusk (1 if dusk roadway; 0 otherwise)	0.03	0.17	0.03	0.17	0.04	0.18	0.03	0.16
Darkness (1 if darkness roadway; 0 otherwise)	0.05	0.22	0.05	0.23	0.06	0.24	0.04	0.20
Daylight (1 if daylight; 0 otherwise)	0.60	0.49	0.62	0.49	0.64	0.48	0.70	0.46
Weather								
Clear (1 if the weather is clear; 0 otherwise)	0.80	0.40	0.79	0.41	0.82	0.39	0.79	0.41
Primary cause								
Disregarding traffic signals (1 if the primary cause of the crash is disregarding traffic signals; 0 otherwise)	0.01	0.12	0.02	0.13	0.01	0.09	0.01	0.09
Operating vehicle in erratic, reckless, careless, negligent or aggressive manner (1 if the primary cause of the crash is Operating vehicle in erratic, reckless, careless, negligent or aggressive manner; 0 otherwise)	0.01	0.13	0.02	0.13	0.03	0.16	0.01	0.10

Table 3 (Continued)

Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	0.23	0.42	0.30	0.46	0.29	0.45	0.37	0.37
Unable to determine (1 if the primary cause of the crash is unable to determine; 0 otherwise)	0.28	0.45	0.26	0.44	0.23	0.42	0.24	0.43
Vision obscured (1 if the primary cause of the crash is vision obscured)	0.23	0.15	0.03	0.16	0.02	0.15	0.03	0.17
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	0.02	0.14	0.02	0.14	0.02	0.13	0.01	0.10
Traffic control device condition								
Functioning improperly (1 if traffic control device condition is functioning improperly; 0 otherwise)	0.02	0.14	0.03	0.17	0.04	0.20	0.04	0.20
Functioning properly (1 if traffic control device condition is functioning properly; 0 otherwise)	0.37	0.48	0.50	0.50	0.45	0.50	0.54	0.50
Intersection related								
Intersection related (1 if collision on intersection; 0 otherwise)	0.47	0.50	0.63	0.48	0.53	0.50	0.67	0.47
Hit and run crash								
Hit and run (1 if hit and run crash; 0 otherwise)	0.38	0.49	0.32	0.47	0.31	0.46	0.22	0.41
Roadway alignment								
Straight (1 if roadway alignment is straight and level; 0 otherwise)	0.97	0.17	0.97	0.17	0.96	0.18	0.98	0.14
Roadway description								
Divided with median barrier (1 if colission is on divided with median barrier road segment; 0 otherwise)	0.07	0.25	0.08	0.27	0.09	0.28	0.09	0.29

Table 3 (Continued)

Divided without median barrier (1 if colission is on divided without median barrier road segment; 0 otherwise)	0.37	0.48	0.39	0.48	0.45	0.50	0.38	0.38
Roadway functional class								
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	0.24	0.42	0.18	0.38	0.14	0.35	0.13	0.34
Other principal arterial (1 if road functional class is other principal arterial; 0 otherwise)	0.18	0.38	0.22	0.41	0.21	0.41	0.20	0.40
Collector (1 if road functional class is collector (urban); 0 otherwise)	0.25	0.43	0.28	0.45	0.27	0.45	0.32	0.46
Interstate (1 if road functional class is interstate; 0 otherwise)	0.01	0.08	0.00	0.06	0.01	0.09	0.00	0.07
Work zone								
Work zone (1 if crash on work zone related road segment; 0 otherwise)	0.13	0.12	0.01	0.10	0.01	0.11	0.00	0.07
Age								
Old (1 if pedestrian is older than 70 years old, 0 otherwise)	0	0	0	0	0.26	0.44	0.30	0.46

3.2 Likelihood Ratio Tests

As a discussion in the methodology chapter, the model and resulting log-likelihood at convergence for the full-sample model (all age and gender groups) was estimated. Second, the models and resulting log-likelihoods at convergence for each gender and age combination were estimated. Finally, the resulting log-likelihood ratio test results are shown in Tables 4 through 6.

3.2.1 Likelihood Ratio Test for Age

Based on Tables 2 through 4, the log-likelihood at convergences for the full model (all age and gender categories) is -4724.80 with the number of observations equal to 4,829; the log-likelihood at convergence for the age less than 50 years old models is -3275.63 with the number of observations equal to 3,405; and the log-likelihood at convergence for 50 years old and older model is -1356.79 with the number of observations equal to 1,354. This gives,

$$X^2 = -2[LL(\boldsymbol{\beta}_{\text{full}}) - LL(\boldsymbol{\beta}_{\text{older}}) - LL\ (\boldsymbol{\beta}_{\text{younger}})]$$

$$X^2 = -2[(-\ 4724.80) - (-\ 3275.63) - (-\ 1356.79)]$$

$$X^2 = 220.76$$

The degrees of freedom for this test is 16 which comes from the number of estimated parameters for the less than 50 years-old model plus number of estimated parameters for greater than 50 years-old model minus the number of estimated parameters for the full model.

Using a Chi-square calculator, the null hypothesis that the full sample model and the two age sub-models are equal can be rejected with more than 99% confidence, suggesting separate older and younger models are warranted.

Table 4 Mixed logit severity model results for base model

Variable	Parameter estimate	t- statistic	Elasticity		
			No injury	Minor injury	Severe injury
Defined for severe injury					
Young (1 if pedestrian is younger than 30 years old, 0 otherwise)	-0.563	-3.96	5.6%	1.5%	-20.0%
Male (1 if pedestrian is male, 0 otherwise)	0.156	1.76	-2.1%	-0.6%	6.1%
Working (1if pedestrian is working in roadway, 0 otherwise)	-0.916	-2.02	0.2%	0.0%	-1.2%
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-0.995	-5.87	1.4%	1.4%	-6.7%
Traffic signal (1 if traffic control device is traffic signal; 0 otherwise)	0.375	3.19	-3.7%	-1.1%	10.5%
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-0.279	-2.16	1.1%	0.2%	-4.3%
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.002	7.48	-16.3%	17.1%	-16.3%
S*tandard deviation of City streets urban roads (normally distributed)*	3.803	3.88			
Crossing – with signal (1if pedestrian action is crossing – with signal, 0 otherwise)	0.353	2.46	-2.2%	2.0%	-2.2%
Crossing – against signal (1if pedestrian action is crossing – against signal, 0 otherwise)	0.553	2.63	-1.3%	1.0%	-1.3%
Walking with traffic (1 if pedestrian is walking with traffic; 0 otherwise)	0.660	2.40	-1.0%	0.8%	-1.0%
Crosswalk not available (1 if pedestrian location is not available crosswalk; 0 otherwise)	1.097	2.06	-0.5%	0.3%	-0.5%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.149	-2.33	0.4%	-0.5%	0.4%
Interstate (1 if road functional class is interstate; 0 otherwise)	-1.471	-2.24	0.1%	-0.5%	0.1%
Defined for no injury					
Young (1 if pedestrian is younger than 30 years old, 0 otherwise)	-0.377	-2.88	-7.7%	2.4%	9.4%
Not at intersection (1if pedestrian entering/leaving/crossing is not at intersection, 0 otherwise)	-0.429	-2.35	-1.3%	0.3%	1.0%
Contrasting clothing (1 if pedestrian visibility is contrasting clothing, 0 otherwise)	-0.183	-1.67	-1.5%	0.4%	1.6%
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.321	9.98	52.7%	-15.9%	-67.7%
Dry (1 if road surface condition is dry; 0 otherwise)	-0.183	-1.95	-6.6%	2.0%	7.4%
Daylight (1 if daylight; 0 otherwise)	0.167	1.91	4.8%	-1.5%	-5.7%
Dawn (1 if dawn roadway; 0 otherwise)	0.777	2.13	0.4%	-0.2%	-0.7%

Table 4 (Continued)

Exceeding authorized speed limit (1 if the primary cause of the crash is exceeding authorized speed limit; 0 otherwise)	-0.975	-1.86	-0.4%	0.1%	0.2%
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	-0.408	-4.30	-5.8%	1.5%	5.7%
Following too closely (1 if the primary cause of the crash is following too closely; 0 otherwise)	1.865	2.56	0.2%	-0.3%	-0.8%
Under the influence of alcohol/drugs (1 if the primary cause of the crash is being under the influence of alcohol/drugs; 0 otherwise)	-2.945	-2.79	-1.3%	0.0%	0.1%
Driving skills/knowledge/experience (1 if the primary cause of the crash is due to driving skills/knowledge/experience; 0 otherwise)	0.500	1.79	0.4%	-0.2%	-0.8%
Disregarding traffic signals (1 if the primary cause of the crash is disregarding traffic signals; 0 otherwise)	-1.020	-2.71	-0.9%	0.1%	0.5%
Exceeding safe speed for conditions (1 if the primary cause of the crash is exceeding safe speed for conditions; 0 otherwise)	-1.794	-2.66	-0.6%	0.0%	0.2%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.282	-4.32	-1.6%	0.2%	0.8%
Operating vehicle in erratic, reckless, careless, negligent or aggressive manner (1 if the primary cause of the crash is Operating vehicle in erratic, reckless, careless, negligent or aggressive manner; 0 otherwise)	-0.580	-1.84	-0.5%	0.1%	0.5%
No controls (1 if there is no traffic control device, 0 otherwise)	-0.436	-2.66	-9.5%	2.7%	10.7%
Hit and run (1 if hit and run crash; 0 otherwise)	0.177	1.99	2.6%	-0.9%	-3.2%
Model statistics					
Number of observations			4829		
Log likelihood at constant			-5305.20		
Log likelihood at convergence			-4724.80		

Table 5 Mixed logit severity model results for pedestrians under 50 years old

Variable	Parameter estimate	t- statistic	Elasticity		
			No injury	Minor injury	Severe injury
Defined for severe injury					
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-1.253	-4.74	2.3%	0.9%	-6.8%
Traffic signal (1 if traffic control device is traffic signal; 0 otherwise)	0.670	3.47	-6.2%	-0.8%	15.7%
Darkness (1 if darkness roadway; 0 otherwise)	0.453	1.70	-0.7%	-0.1%	1.4%
Vision obscured (1 if the primary cause of the crash is vision obscured)	0.933	2.53	-0.9%	-0.1%	1.3%
Not in available crosswalk (1 if pedestrian location is not in available crosswalk; 0 otherwise)	-0.581	-2.02	0.6%	0.1%	-2.3%
Operating vehicle in erratic, reckless, careless, negligent or aggressive manner (1 if the primary cause of the crash is Operating vehicle in erratic, reckless, careless, negligent or aggressive manner; 0 otherwise)	1.258	2.61	-0.7%	-0.1%	0.9%
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.359	3.54	-7.3%	6.7%	-4.1%
Standard deviation of City streets urban roads (normally distributed)	10.431	2.26			
No contrasting clothing (1 if pedestrian visibility is no contrasting clothing, 0 otherwise)	0.747	1.67	-3.7%	3.8%	-3.1%
Standard deviation of No contrasting clothing (normally distributed)	3.471	1.91			
In crosswalk (1if pedestrian location is in crosswalk, 0 otherwise)	0.871	0.44	-3.2%	2.7%	-3.4%
Crosswalk not available (1 if pedestrian location is not available crosswalk; 0 otherwise)	2.651	1.66	-0.5%	0.2%	-0.5%
Interstate (1 if road functional class is interstate; 0 otherwise)	-3.469	-1.58	0.1%	-0.7%	0.1%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-2.916	-1.87	0.4%	-0.7%	0.4%
Defined for no injury					
Hit and run (1 if hit and run crash; 0 otherwise)	0.529	1.94	2.9%	-2.4%	3.9%
Standard deviation of Hit and run (normally distributed)	1.974	2.84			
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.800	9.47	50.3%	-8.1%	-94.0%
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	-0.568	-3.78	-5.4%	0.7%	7.7%
Following too closely (1 if the primary cause of the crash is following too closely; 0 otherwise)	2.455	1.74	0.1%	-0.2%	-1.3%
Disregarding traffic signals (1 if the primary cause of the crash is disregarding traffic signals; 0 otherwise)	-1.355	-2.80	-1.1%	0.1%	0.8%

Table 5 (Continued)

Exceeding safe speed for conditions (1 if the primary cause of the crash is exceeding safe speed for conditions; 0 otherwise)	-2.353	-2.77	-0.9%	0.0%	0.3%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.670	-4.40	-1.9%	0.1%	1.1%
Not at intersection (1if pedestrian entering/leaving/crossing is not at intersection, 0 otherwise)	-0.642	-2.35	-1.4%	0.2%	1.6%
Walking against traffic (1 if pedestrian is walking against traffic; 0 otherwise)	-0.527	-2.08	-1.3%	0.2%	1.7%
Other (1 if pedestrian action is other; 0 otherwise)	-0.388	-2.27	-2.3%	0.3%	3.5%
Not divided (1 if collision is not on divided road segment; 0 otherwise)	0.201	1.50	1.8%	-0.4%	-3.5%
Intoxicated pedestrian (1 if pedestrian is an intoxicated pedestrian; 0 otherwise)	-0.879	-2.03	-0.8%	0.1%	0.8%
No controls (1 if there is no traffic control device, 0 otherwise)	-0.640	-3.62	-9.9%	1.5%	15.9%
Model statistics					
Number of observations			3405		
Log likelihood at constant			-3740.77		
Log likelihood at convergence			-3275.63		

Table 6 Mixed logit severity model results for pedestrians 50 years old and older

Variable	Parameter estimate	t- statistic	Elasticity		
			No injury	Minor injury	Severe injury
Defined for severe injury					
Old (1 if pedestrian is older than 70 years old, 0 otherwise)	0.426	1.61	-2.8%	-1.3%	9.1%
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-1.546	-4.32	3.2%	3.2%	-10.9%
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-0.429	-1.53	0.9%	0.3%	-5.0%
Not at intersection (1if pedestrian entering/leaving/crossing is not at intersection, 0 otherwise)	0.618	2.12	-1.3%	-0.6%	2.5%
One-way or ramp (1 if collision is on one-way or ramp road segment; 0 otherwise)	-0.455	-1.54	0.9%	0.3%	-4.5%
Other principal arterial (1 if road functional class is other principal arterial; 0 otherwise)	0.342	1.69	-2.1%	-1.2%	4.9%
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.490	5.03	-35.7%	41.5%	-35.7%
S*tandard deviation of City streets urban roads (normally distributed)*	2.456	2.16			
Crossing- against signal (1 if pedestrian action is crossing- against signal; 0 otherwise)	0.743	2.20	-2.3%	1.9%	-2.8%
Walking with traffic (1 if pedestrian is walking with traffic; 0 otherwise)	0.773	1.66	-1.4%	1.1%	-1.4%
Other (1 if pedestrian action is other; 0 otherwise)	0.777	2.48	-3.5%	2.9%	-3.5%
Straight (1 if roadway alignment is straight and level; 0 otherwise)	-0.680	-2.36	18.1%	-20.2%	18.1%
Defined for no injury					
Old (1 if pedestrian is older than 70 years old, 0 otherwise)	0.687	2.81	9.1%	-4.5%	-10.1%
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.550	6.49	71.2%	-25.7%	-68.5%
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	-0.363	-2.17	-7.0%	2.0%	5.0%
Under the influence of alcohol/drugs (1 if the primary cause of the crash is being under the influence of alcohol/drugs; 0 otherwise)	-1.656	-1.46	-1.0%	0.1%	0.2%
Darkness and lighted (1 if darkness and lighted roadway; 0 otherwise)	-0.329	-1.86	-4.2%	1.3%	3.2%
Clear (1 if the weather is clear; 0 otherwise)	-0.646	-3.32	-28.6%	9.6%	23.4%
Functioning properly (1 if traffic control device condition is functioning properly; 0 otherwise)	-0.290	-1.96	-8.1%	2.6%	6.2%
Divided without median barrier (1 if collision is on divided without median barrier road segment; 0 otherwise)	-0.249	-1.69	-6.0%	1.8%	4.4%

Table 6 (Continued)

Model statistics	
Number of observations	1354
Log likelihood at constant	-1487.52
Log likelihood at convergence	-1356.79

3.2.2 Likelihood Ratio Test for Younger Males and Females

Based on Table 3, Table 5, and Table 6, the log-likelihood at convergence for the full-sample younger model (age less than 50 years old) is -3275.63 with a number of observations of 3,405; the log-likelihood at convergence for the younger male-only model is -1714.47 with the number of observations equal to 1,773; and log-likelihood at convergence for the younger female-only model -1547.28 with the number of observations equal to 1,632.

$$X^2 = -2[LL\ (\boldsymbol{\beta}_{\text{full}}) - LL\ (\boldsymbol{\beta}_{\text{male}}) - LL\ (\boldsymbol{\beta}_{\text{female}})]$$

$$X^2 = -2[(-3275.63) - (-1714.47) - (-1547.28)]$$

$$X^2 = 27.76$$

Moreover, the degrees of freedom for this test is 12 which came from the number of estimated parameters for male model plus the number of estimated parameters for the female model minus the number of estimated parameters for the base model.

Using a Chi-square calculator, the null hypothesis that the younger age group with both genders and the two gender sub-models are equal can be rejected with more than 99% confidence, suggesting separate younger male/female models are warranted.

3.2.3 Likelihood Ratio Test for Older Males and Females

Based on Table 4, Table 7, and Table 8, log-likelihood at convergence for the full-sample older model (age 50 years old and older) is -1356.78 with number of observations of 1,354; the log-likelihood at convergence for the older male model is -697.58 with the number of observations equal to 705; and the log-likelihood at convergence for the older female model is -642.25 with a number of observations of 649. The test statistic is,

$$X^2 = -2[LL(\boldsymbol{\beta}_{\text{full}}) - LL(\boldsymbol{\beta}_{\text{male}}) - LL(\boldsymbol{\beta}_{\text{female}})]$$

$$X^2 = -2[(-1356.78) - (-697.58) - (-642.25)]$$

$$X^2 = 33.9$$

Moreover, the degrees of freedom for this test is 19, which is the number of estimated parameters for male model plus the number of estimated parameters for female model minus the number of estimated parameters for base model.

Using a Chi-square calculator, the null hypothesis that the older age group with both genders and the two gender sub-models are equal can be rejected with more than 99.4% confidence, suggesting separate older male/female models are warranted.

3.3 Model Estimation Results

Based on the log-likelihood ratio tests, four injury-severity models were warranted; male pedestrians under 50 years old, female pedestrians under 50 years old, male pedestrians 50 years old and older, and female pedestrians 50 years old and older. Model estimation results showed that unobserved heterogeneity was not a significant factor in the male and female models for people 50 years old and older (likelihood ratio tests indicated that the null hypothesis that multinomial and mixed models were equal, and that multinomial and latent-class models were equal, could not be rejected). Thus, for these two sub-groups a conventional multinomial logit model was estimated. For male and female pedestrians under 50 years old, unobserved heterogeneity was statistically significant (likelihood ratio tests indicated that the null hypothesis that multinomial and mixed models were equal, and that multinomial and latent-class models were equal, could be rejected with over 99% confidence). Because mixed and latent class models cannot be directly compared statistically (see Mannering et al., 2016), we estimated both mixed and latent class models for the younger age group.

Given the above results, the following models were estimated:

1. Mixed logit severity model for male pedestrians under 50 years old
2. Mixed logit severity model for female pedestrians under 50 years old
3. Multinomial logit severity model for male pedestrians 50 years old and older
4. Multinomial logit severity model for female pedestrians above 50 years old and older
5. Latent class multinomial logit severity model for male pedestrians under 50 years old
6. Latent class multinomial logit severity model for female pedestrians under 50 years old

The mixed logit, multinomial logit, and latent class logit estimation results are shown in Tables 7 through 12. Tables 7 and 8 show the estimation results of mixed logit model for younger males and younger females. Tables 9 and 10 show the estimation results of multinomial logit model for older males and older females. Tables 11 and 12 show the estimation results of latent class logit model for younger males and younger females.

As previously mentioned, the consideration of choosing the standard multinomial logit model in this study was because some of the models did not have significant unobserved heterogeneity. Moreover, to test for possible specification errors in the multinomial logit structure, nested logit models were run but they were found to be not statistically different from the simple multinomial logit formulation.

As represented in the results from Tables 7 through 12, there are only 8 variables that gave an effect on injury severity for all models. They are (i) city streets urban roads, (ii) state numbered urban roads, (iii) failing to yield right-of way, (iv) failing to reduce speed to avoid crash, (v) not at intersection, (vi) dry, (vii) no controls, and (viii) local road or street. The comparison between each of the models on these variables is presented in the next chapter. Other variables were found to affect injury severity in one or two of gender/age models.

Table 7 Mixed logit severity model results for male pedestrians under 50 years old

Variable	Parameter estimate	t- statistic	Elasticity		
			No injury	Minor injury	Severe injury
Defined for severe injury					
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-1.841	-6.63	2.1%	2.1%	-11.8%
Darkness (1 if darkness roadway; 0 otherwise)	0.618	2.13	-0.9%	-0.5%	2.4%
Other (1 if pedestrian action is other; 0 otherwise)	0.363	2.07	-1.5%	-0.9%	5.0%
In roadway (1 if pedestrian location is in roadway; 0 otherwise)	0.278	1.95	-3.0%	-1.8%	10.8%
Darkness and lighted (1 if darkness and lighted roadway; 0 otherwise)	0.356	2.31	-2.3%	-1.4%	8.2%
Functioning improperly (1 if traffic control device condition is functioning improperly; 0 otherwise)	1.302	3.07	-1.0%	-0.7%	1.7%
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.676	11.62	-56.0%	52.6%	-56.0%
Standard deviation of City streets urban roads (normally distributed)	1.413	1.59			
Crosswalk not available (1 if pedestrian location is not available crosswalk; 0 otherwise)	0.943	1.51	-0.7%	0.3%	-0.7%
Defined for no injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	2.005	10.34	105.1%	-44.4%	-78.8%
Failing to yield right- of way (1 if the primary cause of the crash is failing to yield right- of way; 0 otherwise)	-0.420	-2.75	-6.1%	2.1%	3.7%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.123	-2.16	-1.7%	0.3%	0.5%
Not at intersection (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)	-0.610	-2.09	-2.3%	0.6%	1.0%
Intoxicated pedestrian (1 if pedestrian is an intoxicated pedestrian; 0 otherwise)	-0.511	-1.43	-1.1%	0.3%	0.5%
Traffic signal (1 if traffic control device is traffic signal; 0 otherwise)	-0.282	-1.75	-5.3%	2.3%	3.8%
Dry (1 if road surface condition is dry; 0 otherwise)	-0.276	-2.13	-12.6%	4.9%	8.5%
Dusk (1 if dusk roadway; 0 otherwise)	-0.821	-2.08	-1.7%	0.4%	0.7%
No controls (1 if there is no control device; 0 otherwise)	-0.457	-2.88	-15.2%	5.6%	9.8%
Divided without median barrier (1 if collision is on divided without median barrier road segment; 0 otherwise)	-0.189	-1.55	-4.3%	1.6%	2.7%

Table 7 (Continued)

Model statistics	
Number of observations	1773
Log likelihood at constant	-1947.84
Log likelihood at convergence	-1714.47

Table 8 Mixed logit severity model results for female pedestrians under 50 years old

Variable	Parameter estimate	t- statistic	Elasticity		
			No injury	Minor injury	Severe injury
Defined for severe injury					
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-0.832	-2.76	1.0%	1.1%	-5.6%
Traffic signal (1 if traffic control device is traffic signal; 0 otherwise)	0.666	2.98	-5.2%	-2.9%	22.0%
Vision obscured (1 if the primary cause of the crash is vision obscured)	0.788	1.62	-0.4%	-0.3%	1.4%
Operating vehicle in erratic, reckless, careless, negligent or aggressive manner (1 if the primary cause of the crash is operating vehicle in erratic, reckless, careless, negligent or aggressive manner; 0 otherwise)	1.595	2.69	-0.7%	-0.6%	1.6%
Crossing- with signal (1 if pedestrian action is crossing- with signal; 0 otherwise)	-0.450	-2.25	2.0%	1.1%	-12.3%
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-0.441	-1.63	0.7%	0.7%	-6.2%
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.305	6.16	-35.4%	36.0%	-34.6%
S*tandard deviation of City streets urban roads (normally distributed)*	1.727	2.30			
Crosswalk not available (1 if pedestrian location is not available crosswalk; 0 otherwise)	1.433	1.73	-0.8%	0.4%	-1.1%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.946	-3.31	0.9%	-2.0%	1.0%
Intersection related (1 if collision on intersection; 0 otherwise)	0.437	2.64	-9.7%	8.4%	10.8%
Divided with median barrier (1 if collision is on divided with median barrier road segment; 0 otherwise)	0.542	1.82	-1.6%	1.1%	1.9%
Other principal arterial (1 if road functional class is other principal arterial; 0 otherwise)	0.473	2.57	-4.2%	3.2%	-4.9%
Work zone (1 if crash on work zone related road segment; 0 otherwise)	-1.989	-2.31	0.3%	-1.1%	0.4%
Defined for no injury					
No controls (1 if there is no control device; 0 otherwise)	-0.732	-1.83	-1.4%	-0.2%	6.8%
S*tandard deviation of No controls (normally distributed)*	2.243	1.69			
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.487	7.03	59.4%	-28.9%	-55.0%
Failing to yield right- of way (1 if the primary cause of the crash is failing to yield right- of way; 0 otherwise)	-0.401	-2.40	-6.1%	2.4%	4.7%
Disregarding traffic signals (1 if the primary cause of the crash is disregarding traffic signals; 0 otherwise)	-1.469	-2.41	-2.0%	0.3%	0.6%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.691	-3.31	-2.1%	0.6%	0.9%

Table 8 (Continued)

Hit and run (1 if hit and run crash; 0 otherwise)	0.327	1.95	4.4%	-2.4%	-4.3%
Model statistics					
Number of observations			1632		
Log likelihood at constant			-1792.94		
Log likelihood at convergence			-1547.28		

Table 9 Multinomial logit severity model results for male pedestrians 50 years old and older

Variable	Parameter estimate	t- statistic	Elasticity		
			No injury	Minor injury	Severe injury
Defined for severe injury					
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-1.044	-2.53	13.2%	13.2%	-57.3%
Walking with traffic (1 if pedestrian is walking with traffic; 0 otherwise)	-1.326	-1.79	0.4%	0.4%	-6.4%
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	0.402	1.94	-2.7%	-2.7%	9.1%
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.731	4.24	-73.7%	79.3%	-73.7%
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	1.246	2.73	-6.2%	6.9%	-6.2%
Straight (1 if roadway alignment is straight and level; 0 otherwise)	-0.731	-1.84	33.3%	-37.2%	33.3%
Defined for no injury					
Older (1 if pedestrian is older than 70 years older; 0 otherwise)	0.578	3.25	8.6%	-6.6%	-6.6%
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	0.785	3.56	45.0%	-24.4%	-24.4%
Darkness and lighted (1 if darkness and lighted roadway; 0 otherwise)	-0.461	-2.34	-8.1%	3.0%	3.0%
Clear (1 if the weather is clear; 0 otherwise)	-0.308	-1.67	-17.0%	8.2%	8.2%
Stand (1 if pedestrian is standing in roadway; 0 otherwise)	-0.613	-1.68	-3.1%	1.0%	1.0%
One- way or ramp (1 if collision is on one- way or ramp road segment; 0 otherwise)	0.440	1.78	-3.1%	1.0%	1.0%
Collector (1 if road functional class is collector (urban); 0 otherwise)	0.295	1.60	-3.1%	1.0%	1.0%

Model statistics	
Number of observations	705
Log likelihood at constant	-727.33
Log likelihood at convergence	-697.58

Table 10 Multinomial logit severity model results for female pedestrians 50 years old and older

Variable	Parameter estimate	t- statistic	Elasticity		
			No injury	Minor injury	Severe injury
Defined for severe injury					
Older (1 if pedestrian is older than 70 years older; 0 otherwise)	0.732	3.09	-5.1%	-5.1%	16.6%
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-1.903	-3.85	2.1%	2.1%	-12.3%
Not at intersection (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)	0.741	1.91	-1.3%	-1.3%	3.0%
Dry (1 if road surface condition is dry; 0 otherwise)	0.463	1.74	-7.2%	-7.2%	28.6%
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	0.388	1.83	-3.4%	-3.4%	11.1%
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.542	5.50	-67.2%	74.6%	-67.2%
Crossing- against signal (1 if pedestrian action is crossing- against signal; 0 otherwise)	0.913	2.82	-4.2%	2.4%	-4.2%
Other (1 if pedestrian action is other; 0 otherwise)	0.639	2.69	-4.9%	3.8%	-4.9%
Walking against traffic (1 if pedestrian is walking against traffic; 0 otherwise)	0.709	1.97	-2.2%	1.8%	-2.2%
Defined for no injury					
Older (1 if pedestrian is older than 70 years older; 0 otherwise)	0.498	2.52	9.1%	-5.6%	-5.6%
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.631	5.23	99.5%	-50.5%	-50.5%
Functioning properly (1 if traffic control device condition is functioning properly; 0 otherwise)	-0.160	-1.73	-6.1%	2.5%	2.5%
Walking with traffic (1 if pedestrian is walking with traffic; 0 otherwise)	-0.620	-1.57	-2.8%	0.9%	0.9%
Crosswalk (1 if pedestrian location is in crosswalk; 0 otherwise)	-0.317	-1.66	-12.3%	5.1%	5.1%
Unable to determine (1 if the primary cause of the crash is unable to determine; 0 otherwise)	0.360	1.86	5.1%	-3.7%	-3.7%
Divided without median barrier (1 if collision is on divided without median barrier road segment; 0 otherwise)	-0.271	-1.56	-7.3%	3.0%	3.0%

Model statistics	
Number of observations	649
Log likelihood at constant	-670.46
Log likelihood at convergence	-642.25

Table 11 Latent class multinomial logit severity model results for male pedestrians under 50 years old

Variable	Latent class 1		Latent class 2		Elasticity		
	Parameter estimate	**t-statistic**	**Parameter estimate**	**t-statistic**	**No injury**	**Minor injury**	**Severe injury**
Defined for severe injury							
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-0.555	-0.88	-1.946	-3.70	2.2%	1.4%	-8.4%
In roadway (1 if pedestrian location is in roadway; 0 otherwise)	-2.863	-2.44	0.806	3.00	-8.0%	-1.0%	-18.0%
Functioning improperly (1 if traffic control device condition is functioning improperly; 0 otherwise)	-3.399	-0.24	1.751	2.76	-1.3%	-0.6%	0.2%
Defined for minor injury							
Weekend (1 if crash occurred during weekend; 0 otherwise)	2.457	2.82	-2.227	-1.16	-24.5%	-16.6%	-32.2%
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	2.106	2.65	-0.264	-0.32	-7.6%	0.3%	-15.8%
Vision obscured (1 if the primary cause of the crash is vision obscured)	-0.042	-0.04	2.292	1.66	-1.0%	1.1%	-0.7%
One- way or ramp (1 if collision is on one- way or ramp road segment; 0 otherwise)	1.512	1.71	-14.211	-0.01	-10.5%	1.2%	-10.7%
Defined for no injury							
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	-0.847	-1.48	1.425	4.62	13.0%	-15.8%	-47.0%
Dry (1 if road surface condition is dry; 0 otherwise)	-1.216	-1.90	-0.265	-1.04	-28.3%	6.0%	9.0%
Daylight (1 if daylight; 0 otherwise)	-0.269	-0.43	0.422	1.95	2.1%	-3.1%	-8.9%
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	1.283	1.04	-2.087	-1.71	-0.2%	0.0%	0.3%
Other principal arterial (1 if road functional class is other principal arterial; 0 otherwise)	0.695	1.10	-0.654	-2.07	-0.6%	0.5%	3.0%
Class probability	0.532	18.26	0.468	16.09			
Model statistics							
Number of observations			1773				
Log likelihood at convergence			-1771.00				
Restricted log-likelihood			-1947.84				

Table 12 Latent class multinomial logit severity model results for female pedestrians under 50 years old

Variable	Latent class 1		Latent class 2		Elasticity		
	Parameter estimate	**t-statistic**	**Parameter estimate**	**t-statistic**	**No injury**	**Minor injury**	**Severe injury**
Defined for severe injury							
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-1.271	-3.02	-0.142	-0.28	0.9%	1.8%	-12.6%
Not at intersection (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)	-1.915	-0.95	1.869	1.97	-1.6%	0.1%	0.0%
Unable to determine (1 if the primary cause of the crash is unable to determine; 0 otherwise)	-0.613	-1.96	-0.951	-1.84	1.8%	1.8%	-17.6%
Defined for minor injury							
Intersection related (1 if collision on intersection; 0 otherwise)	1.749	4.51	-0.427	-0.43	-30.3%	10.9%	-48.4%
Crossing- against signal (1 if pedestrian action is crossing- against signal; 0 otherwise)	2.360	1.56	-1.846	-0.65	-4.6%	-2.1%	-8.6%
Hit and run (1 if hit and run crash; 0 otherwise)	0.694	2.32	-3.816	-0.22	-8.7%	0.1%	-10.5%
Divided with median barrier (1 if collision is on divided with median barrier road segment; 0 otherwise)	0.408	0.52	1.771	1.93	-3.6%	2.6%	-3.1%
Defined for no injury							
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	-0.431	-0.91	1.385	3.81	6.4%	-12.3%	-37.9%
Walking against traffic (1 if pedestrian is walking against traffic; 0 otherwise)	2.686	2.69	-2.017	-2.07	2.2%	-2.8%	0.3%
No controls (1 if there is no control device; 0 otherwise)	-2.378	-1.80	0.914	1.43	-20.9%	-2.0%	-8.2%
Class probability	0.594	11.38	0.406	7.77			
Model statistics							
Number of observations			1632				
Log likelihood at convergence			-1578.76				
Restricted log-likelihood			-1792.94				

CHAPTER 4: PEDESTRIAN INJURY-SEVERITY ELASTICITIES

To determine the effect of individual variables, it is interesting to study elasticity's or marginal effects generated by the model estimations (the marginal effects can be seen in Appendix A). The elasticity will show the effect of a 1% change in an explanatory variable on the probability of a specific injury-severity outcome. If the explanatory variable is a 0/1 indicator variable, the elasticity presented will give the effect that the explanatory variable has on the probability of a specific injury-severity category when the indicator variable goes from zero to one.

4.1 Effects of City Streets Urban Roads

As shown in Figures 1a and 1b, City streets urban roads indicator variable (1 if collision on city streets urban roads segment; 0 otherwise) is statistically significant in showing the effects of gender and age on resulting injury severities in pedestrian crashes in all six models (mixed logit models for younger male and younger female, multinomial models for older male and older female, and latent class logit models for younger male and younger female). In all of the mixed logit model estimation results (younger males and younger females) and all of the multinomial logit models (older males and older females), the city streets urban roads indicator variable is significant when it is defined for both minor injury and no injury. Because this variable is active in both two minor injury level and no injury level, a careful interpretation of the results is required. When it is defined for minor injury, the likelihood of pedestrians having a minor-injury level will be higher and the likelihood of pedestrians having no-injury and severe-injury levels would be lower. This city streets urban roads indicator variable is a random parameter in both younger male and younger female models only. It means that there is an unobserved heterogeneity in this variable for those two models. In the younger males' model, a positive parameter with a mean of 1.676 and a standard deviation of 1.413, suggesting that for 88.10% of pedestrian crashes involving younger males on city streets urban roads increases the likelihood of minor injury and decreases the likelihood of other types of injuries. However, for 11.9% of pedestrian crashes (the parameter is negative) involving younger males in city streets urban roads decreases the likelihood of minor injury and increases the likelihood of other types of injuries. In the younger females model, a positive parameter with a mean of 1.305 and a standard deviation of 1.727, suggesting that for 77.34% of pedestrian crashes involving younger females in city streets urban roads increases the likelihood of minor injury. However, for 22.66% of pedestrian crashes involving younger females in city streets urban roads decreases the likelihood of minor injury. Moreover, when this variable is defined for no injury in all of the mixed logit models (younger males and younger females) and all of the multinomial logit models (older males and older females), the likelihood of pedestrians having no injury is higher and the likelihood of pedestrians having minor injury and severe injury are lower. Based on these results, older males and older females have higher minor injury likelihoods if they got hit in city streets urban roads. In addition, males have a higher injury severity level relative to females. This seems to lend support to previous findings that females are less likely undertake a risky behavior relative to males (Jones, Gurupackiam, and Walsh, 2013). Therefore, females have lower injury severities.

In all latent class logit model estimation results (younger males and younger females), the city street urban roads indicator variable is statistically significant when it is defined for the no injury level. Latent class model results show a negative sign in one class and a positive sign in another class. The outcomes show that the likelihood of pedestrians (younger males and younger females) having minor injury and severe injury are lower. In addition, the likelihood of pedestrians (younger male and younger female) having no injury is higher.

4.2 Effects of State Numbered Urban Roads

The state numbered urban roads indicator variable is statistically significant in all models except latent class logit model for younger female. As indicated in Figure 2, the state numbered urban roads indicator variable is found to be related to an increase in the likelihood of minor injury and no injury severities when it is defined for no injury in these 4 models (all mixed logit models, multinomial logit model for older females, and latent class logit model for younger males). In the multinomial logit model for older males, this variable is significant when it is defined for minor injury. This variable is related to an increase in the likelihood of minor injury and a decrease in the likelihood of no injury and severe injury.

As shown in Figure 2, the minor severity outcome for older males and older females are higher than younger males and younger females. This is possibly the result of the fact that older people's reaction and response times may be higher than younger people's. This high reaction time may also be correlated with muscle strength. When muscle strength decreases, it means that the time to act and speed of actions will increase.

4.3 Effects of Failing to Yield Right-of Way

As depicted in Figure 3, this variable is statistically significant in all models except in latent class logit model for younger females. In all mixed logit models for younger males and younger females, this variable is significant when it is defined for the no-injury severity. When the primary cause of the crash is failing to yield right-of way, younger males and younger females are more likely to have a lower likelihood of no injury and a higher likelihood of minor injury and severe injury. In all multinomial logit models for older males and older females, failing to yield right-of way indicator variable is significant when it is defined for severe injury. This variable shows that it is found to have a higher likelihood of severe injury and a lower injury of no injury and minor injury.

Furthermore, failing to yield right-of way variable is statistically significant in one of latent class logit models. It is statistically significant when it is defined for minor injury. The results show that this variable is found to have a higher likelihood of minor injury and a lower injury of no injury and severe injury. Based on the results from these all five models, older people will have higher injury severities relative to younger people when the primary cause of the crash is failing to yield right-of way.

4.4 Effects of Failing to Reduce Speed to Avoid Crash

As shown in on Figure 4, the failing to reduce speed to avoid crash indicator variable is statistically significant variable in three models (all mixed logit models for younger males and younger females, and latent class logit model for younger males). This variable is significant when it is defined for the no-injury level. However, these three models show different results. In the mixed logit model for younger males, this variable is found to decrease the likelihood of the no-injury level and an increase the likelihood of minor injury and severe injury. In the mixed logit model for younger females, the failing to reduce speed to avoid crash variable is found to decrease the likelihood of minor injury and increase in the likelihood of no-injury and severe-injury levels. In latent class models for younger males, this variable is associated with an increase in the likelihood of the severe-injury level and a decrease in the likelihood of no-injury and minor-injury levels. Based on the results from these three models, younger females tend to have higher injury severities relative to younger males when the primary cause of the crash is failing to reduce speed to avoid a crash.

4.5 Effects of "Not at Intersection"

As shown in Figure 5, the not-at-intersection indicator variable (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise) is statistically significant in all three models (the mixed logit model for younger males, multinomial logit model for older females, and latent class logit model for younger females). In the mixed logit model for younger males, this variable is significant when it is defined for the no-injury severity level. The variable is found to decrease the likelihood of no injury and an increase in the likelihood of minor injury and severe injury. In the multinomial logit model for older females and latent class logit model for younger females, this not-at-intersection indicator variable is significant when it is defined for severe injury level. In the multinomial logit model for older females, the variable is found to increase the likelihood of severe injury level and a decrease in the likelihood of no injury and minor injury level. In the latent class logit model for younger females, the not-at-intersection variable is related to a decrease in the likelihood of no injury and an increase in the likelihood of severe injury and minor injury. Based on the results in this variable, older females will have higher injury severities when they enter, leave, or cross, not at an intersection.

4.6 Effects of Dry Conditions

Figure 6 shows that the dry indicator variable (1 if road surface condition is dry; 0 otherwise) is statistically significant in three models; the mixed logit model for younger males, the multinomial logit model for older females, and the latent class logit model for younger males. Mixed logit models and latent class logit models for younger males are found to be significant when they are defined for the no-injury level. The dry indicator variable is found to be related to a decrease in the likelihood of the no-injury level and an increase in the likelihood of the minor-injury and severe-injury levels. In the multinomial logit model for older females, the dry variable is significant when it is defined for severe injury. This result shows that an increase of this variable will give an increase in the likelihood of severe injury and a decrease in the likelihood of minor injury and no injury for older females. Based on the results from these three models, younger males, and older males tend to have high severe-injury likelihoods when they get hit by vehicles in dry road conditions. This may be because people who drive a car on dry road conditions may tend to drive at higher speeds.

4.7 Effects of No Control Devices

As depicted in Figure 7, the no-controls indicator variable (1 if there is no control device; 0 otherwise) is found to be statistically significant in the mixed logit model for younger males, the mixed logit model for younger females, and latent class model for younger females. They are significant when they are defined for no injury. However, they have different results. In the mixed logit model for younger males, the no-controls indicator variable is found to be related to a decrease in the likelihood of no injury and an increase in the likelihood of minor injury and severe injury. In the mixed logit model for younger females, the variable is found to be related to an increase in the likelihood of severe injury and a decrease in the likelihood of no injury and minor injury. Moreover, the variable is a random parameter in this model. It means that the effect of this variable is heterogeneous across observations. In younger females model, a negative parameter with a mean of 0.732 and a standard deviation of 2.243, suggesting that for 37.45% of pedestrian crashes involving younger females in a crash where there is no control device there is a decrease in the likelihood of no injury and an increase the likelihood of other types of injuries. However, for 62.55% of pedestrian crashes (the parameter is positive) involving younger females in a crash where there is no control device there is an increase in the likelihood of no injury and a decrease in the likelihood of other types of injuries. Clearly, the effect of no control device can vary across observations. In the latent class logit model for younger females, the variable is found to be related to a decrease in the likelihood of all injury levels (no injury, minor injury, and severe injury).

4.8 Effects of Local Road or Street

Figure 8 shows that the local road or street indicator variable is statistically significant in three models (the mixed logit model for younger females, the multinomial logit model for older males, and the latent class logit model for younger females). They are all significant when they are defined for severe injury. This variable is found to be related to a decrease in the likelihood of severe injury and an increase in the likelihood of minor injury and severe injury. Based on the results, older males have higher injury and minor injury level than younger females when they get hit in a local road or street.

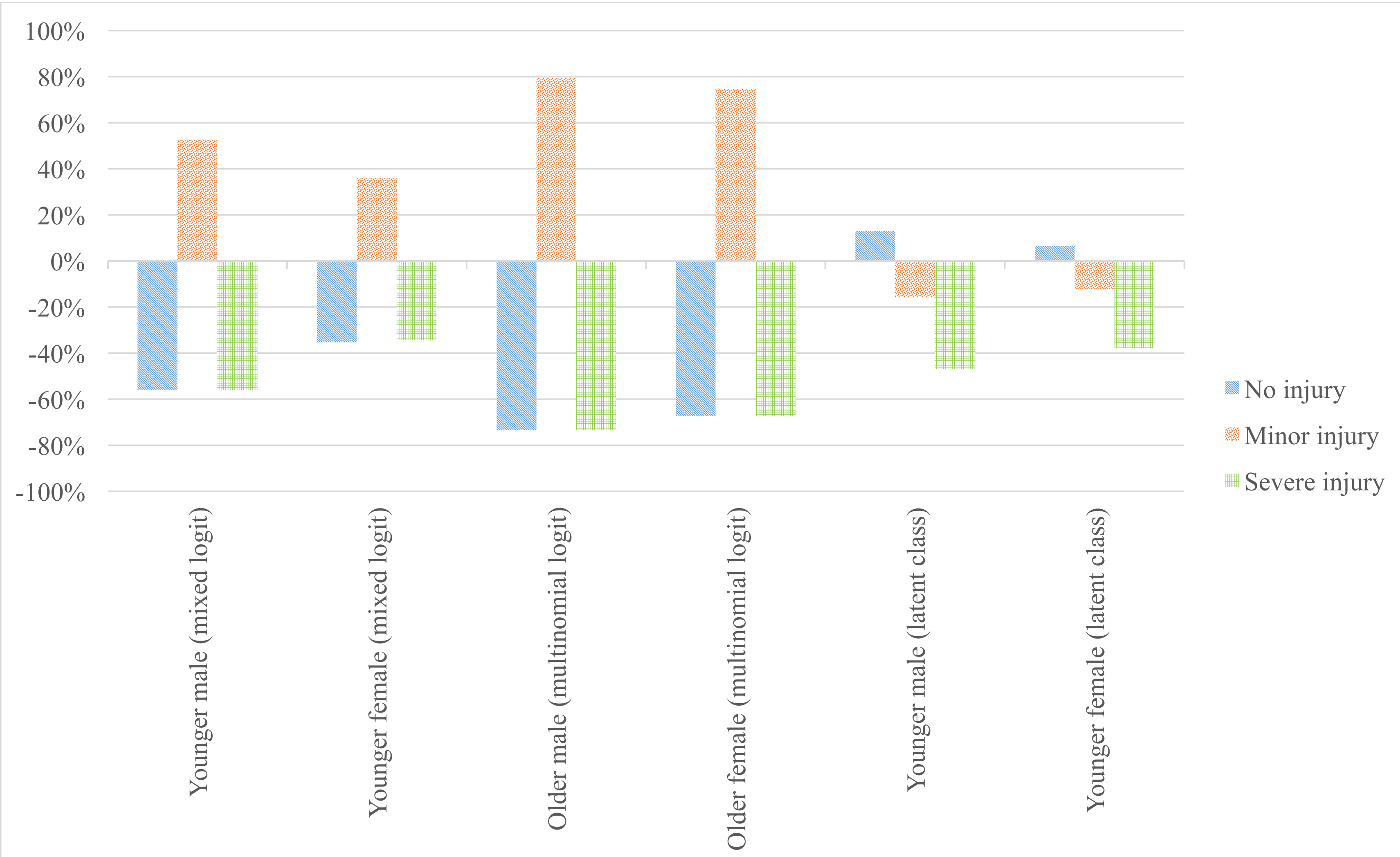

Figure 1a Elasticity for “City streets urban roads” when it is defined for minor injury level (1 if collision on city streets urban roads segment; 0 otherwise)

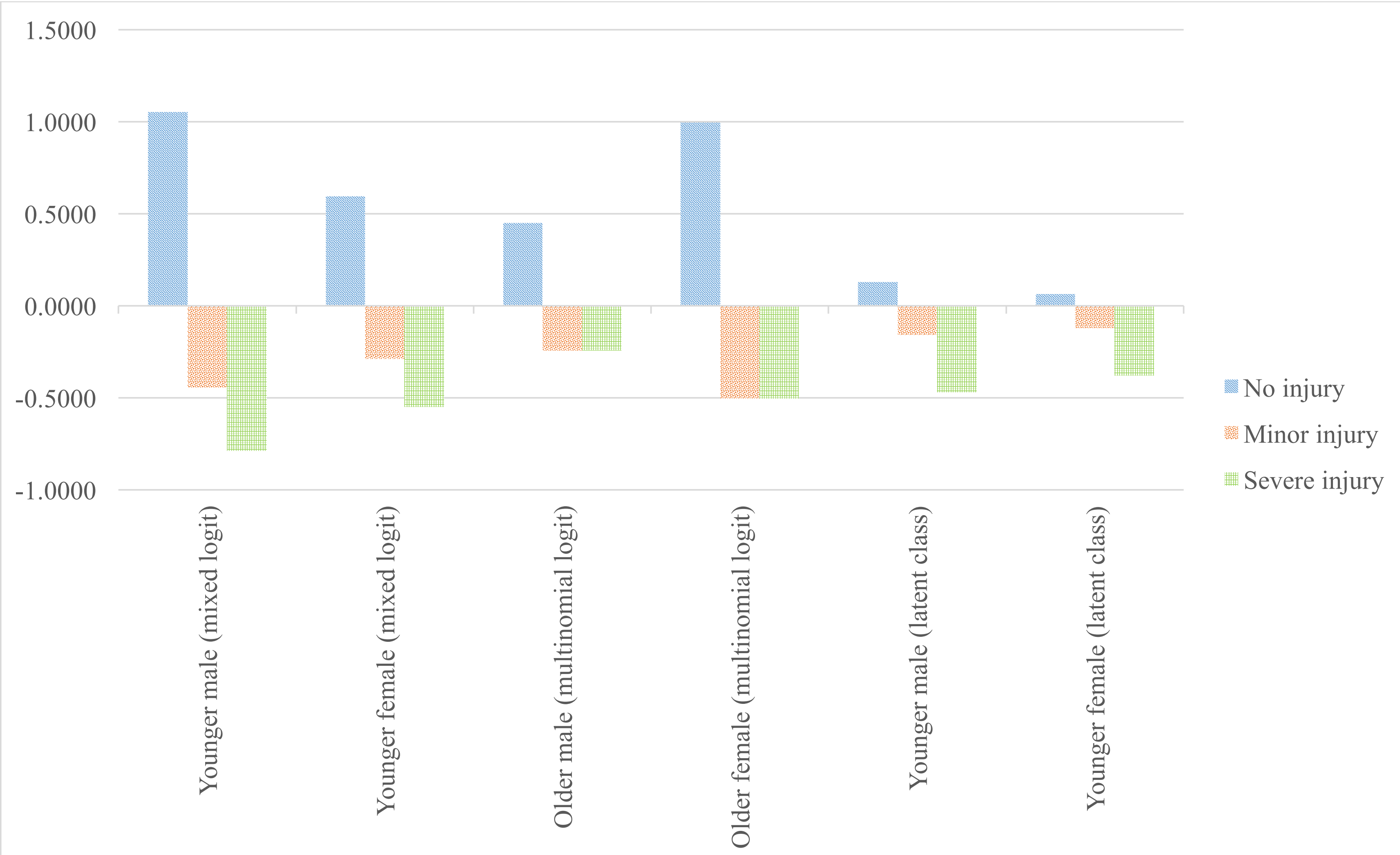

Figure 1b Elasticity for “City streets urban roads” when it is defined for no injury level (1 if collision on city streets urban roads segment; 0 otherwise)

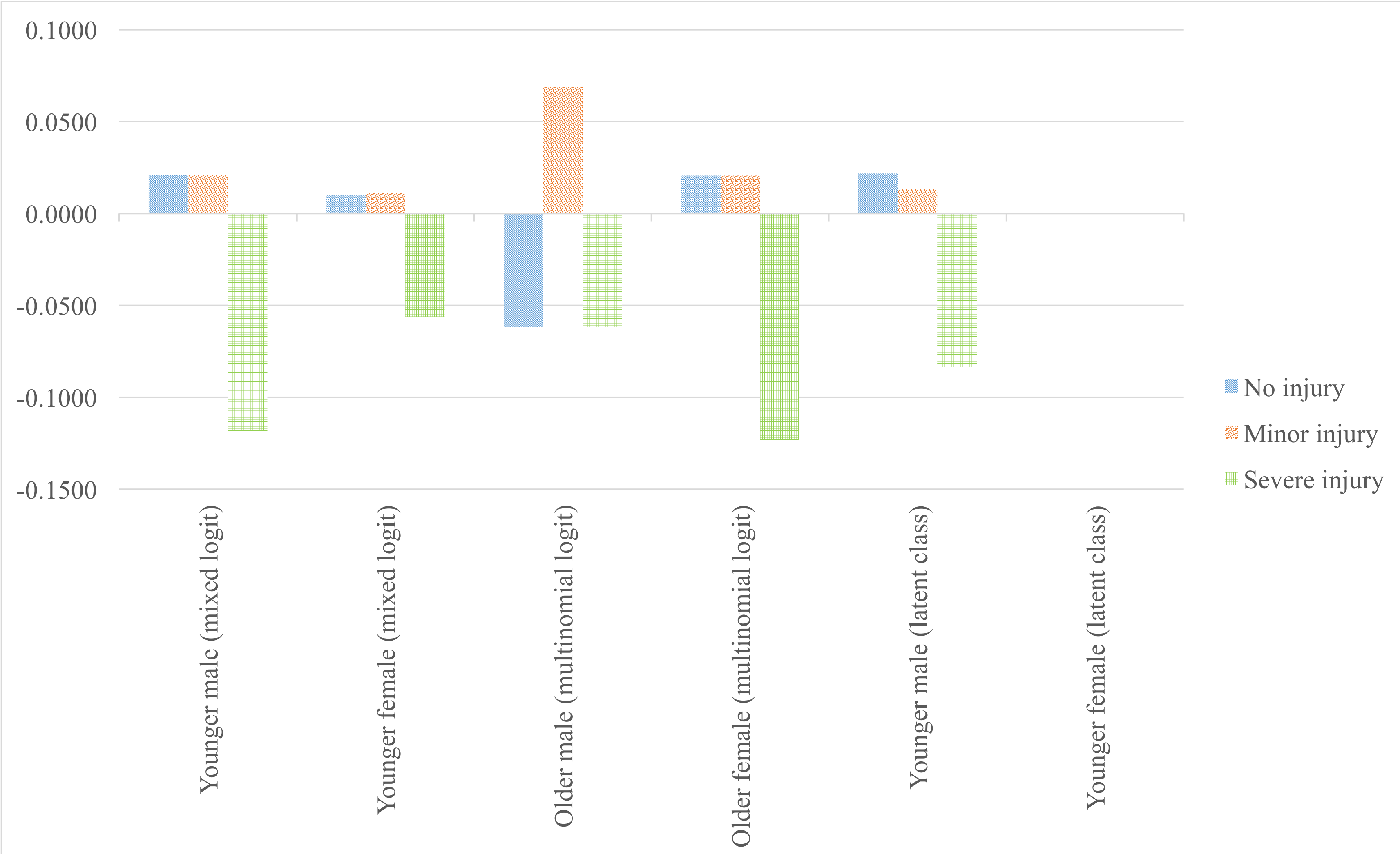

Figure 2 Elasticity for “State numbered urban roads” (1 if collision on state numbered urban roads segment; 0 otherwise)

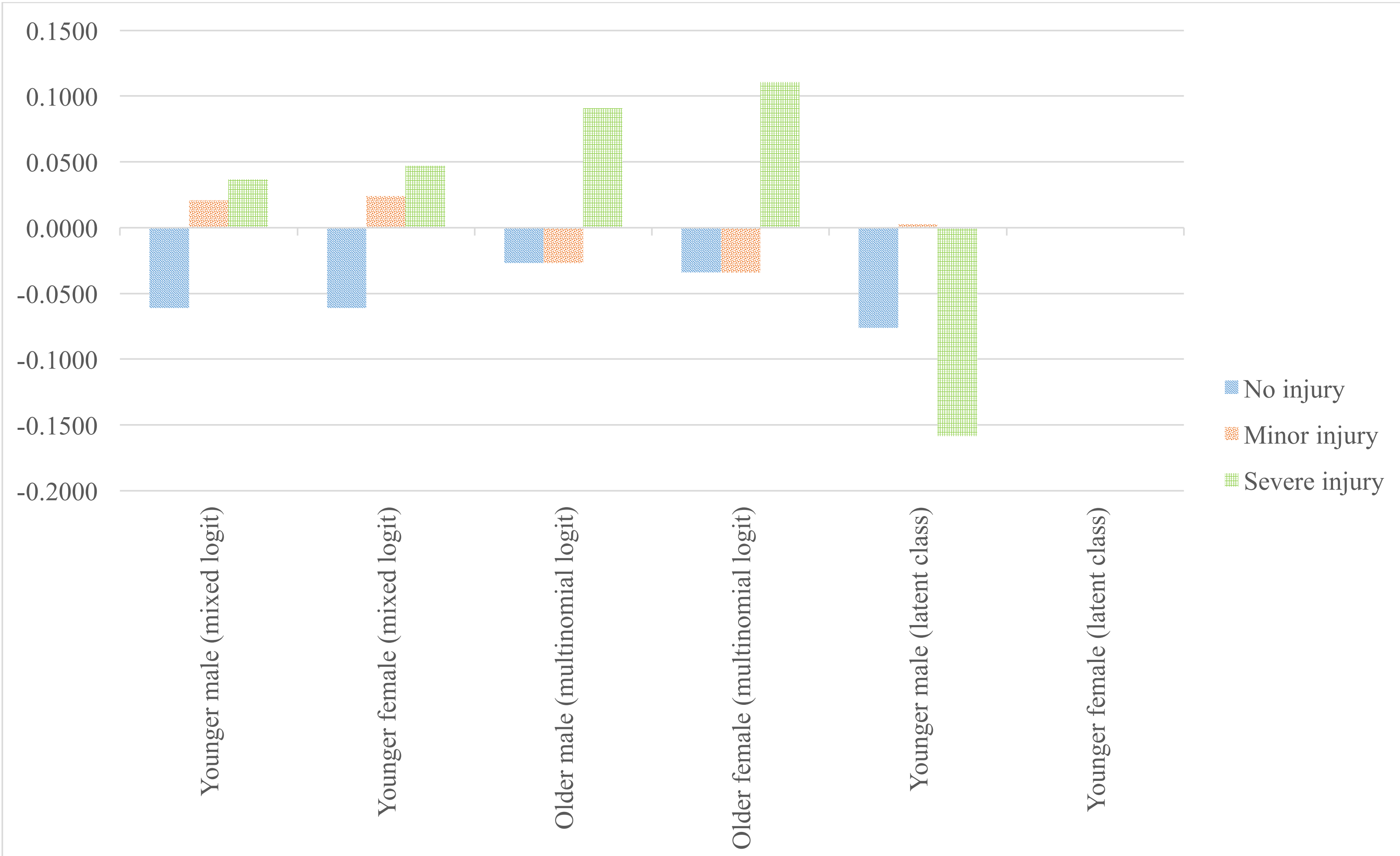

Figure 3 Elasticity for "Failing to yield right-of way" (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)

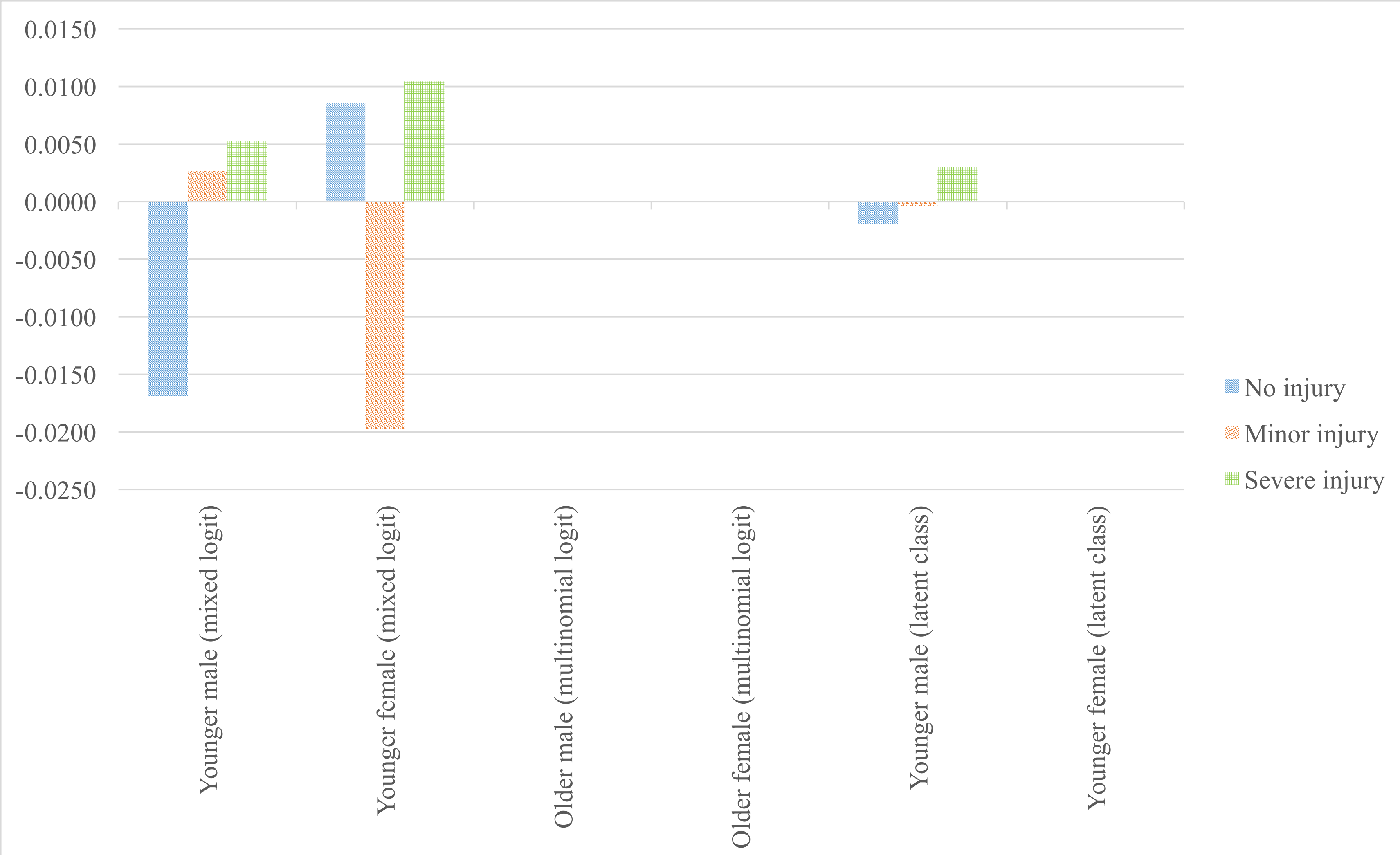

Figure 4 Elasticity for "Failing to reduce speed to avoid crash" (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)

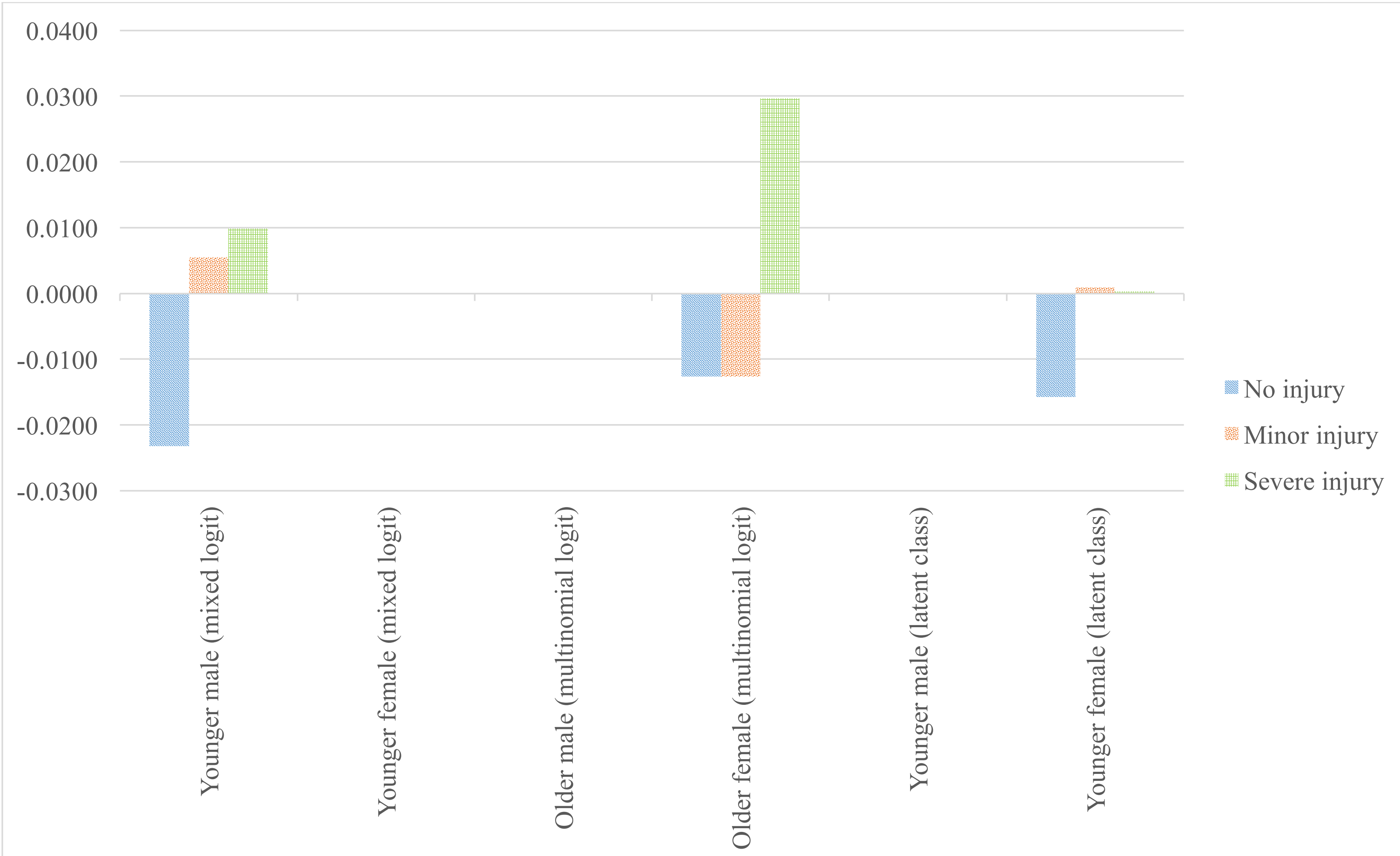

Figure 5 Elasticity for “Not at intersection” (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)

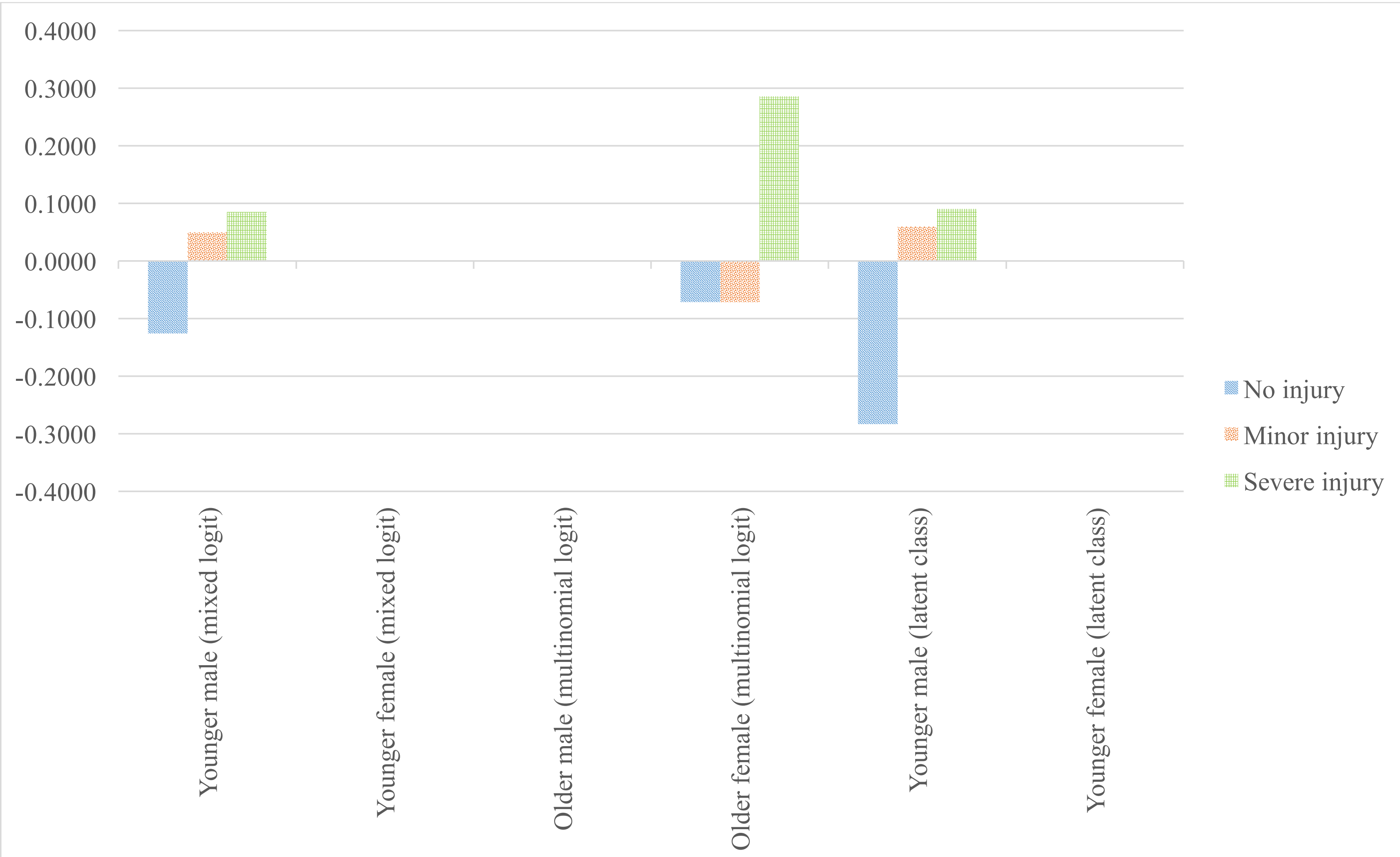

Figure 6 Elasticity for “Dry” (1 if road surface condition is dry; 0 otherwise)

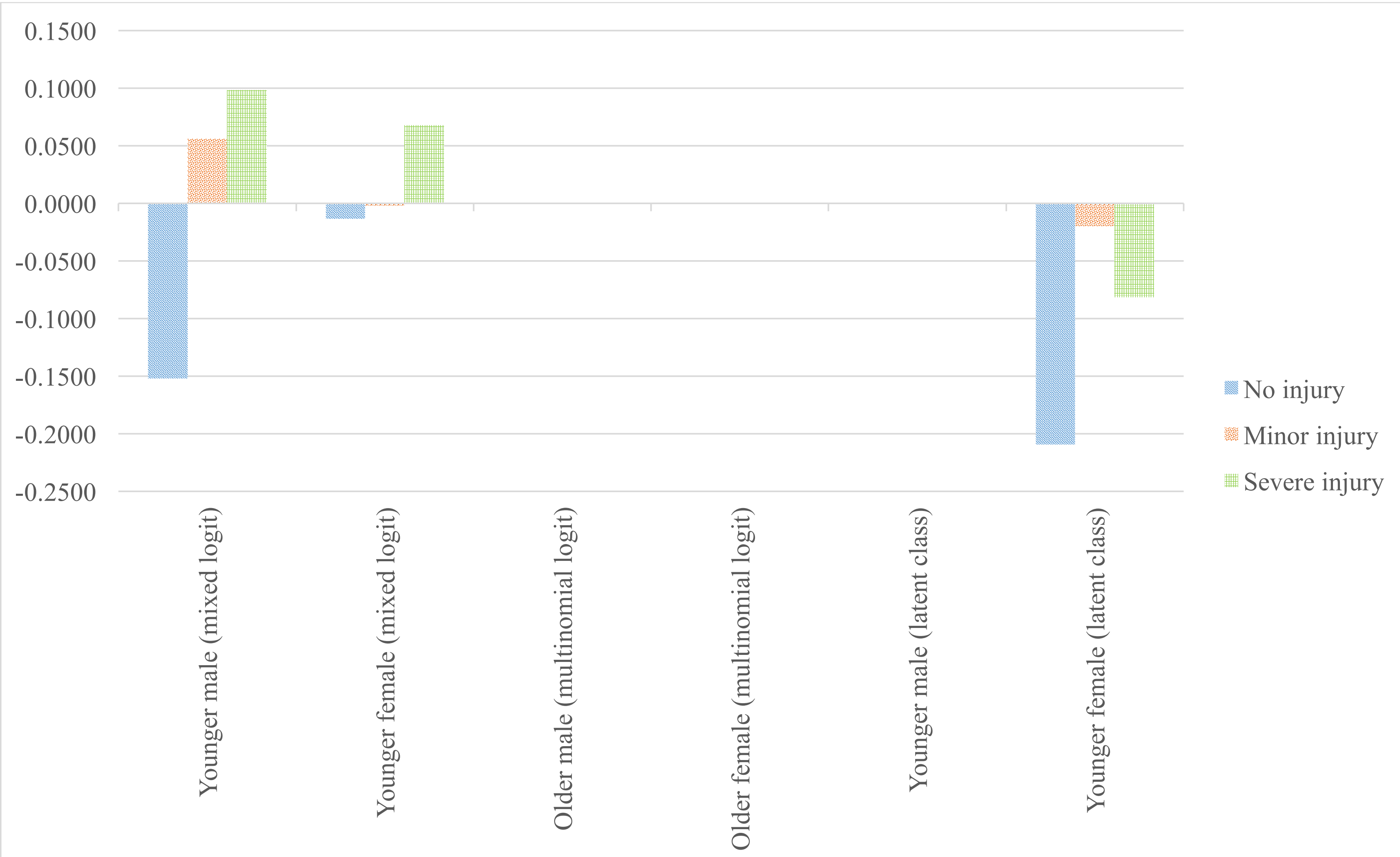

Figure 7 Elasticity for “No controls” (1 if there is no control device; 0 otherwise)

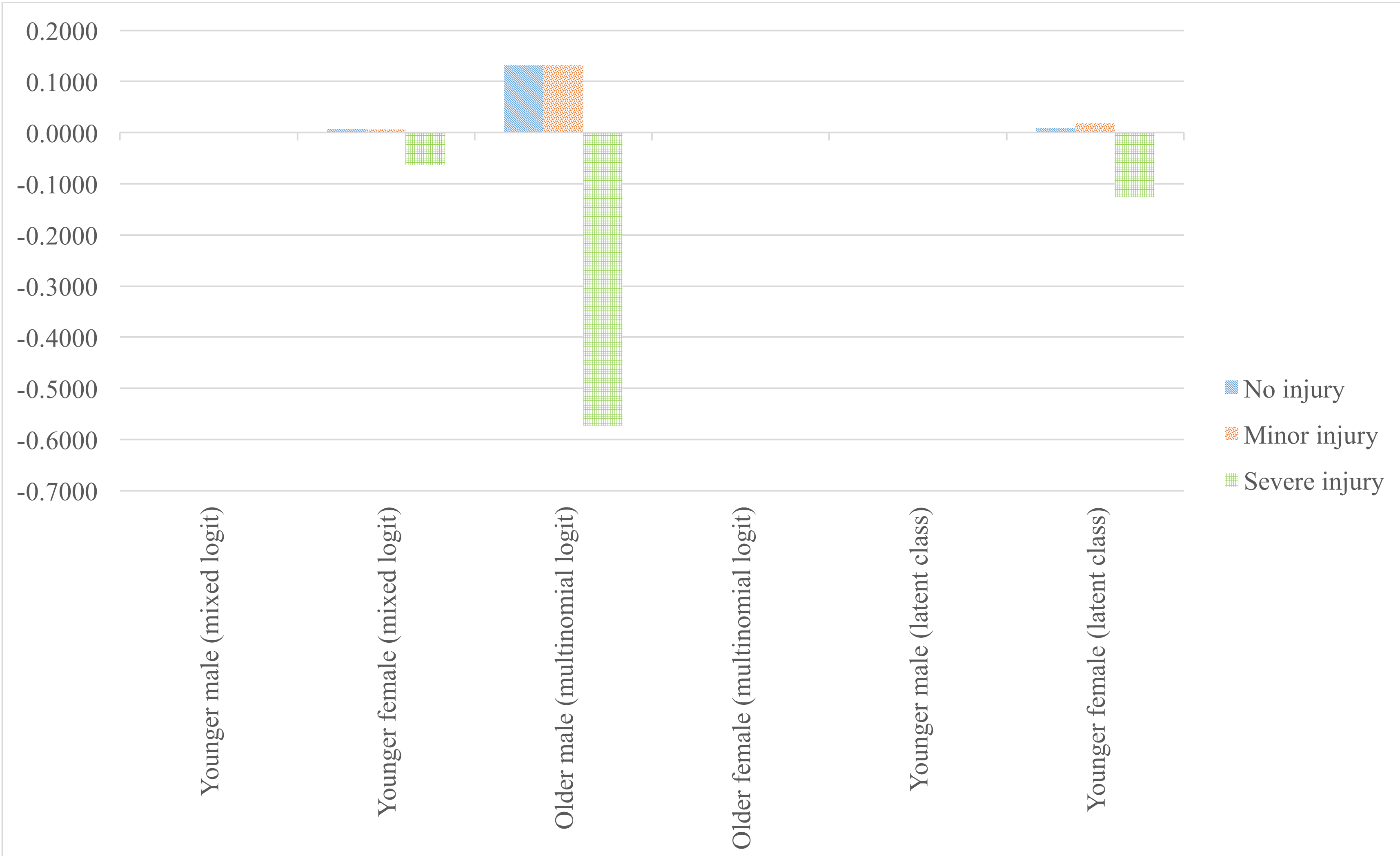

Figure 8 Elasticity for “Local road or street” (1 if road functional class is local road or street (urban); 0 otherwise)

CHAPTER 5: SUMMARY AND CONCLUSIONS

Due to increasing pedestrian fatalities and potential differences in injury levels by age and gender, this paper seeks to analyze the effects of age and gender on resulting injury severities in pedestrian crashes. By using police- reported pedestrian crashes data that were collected in Chicago, multinomial logit models, mixed logit models, and latent class logit models are estimated. There are six models that are estimated with the injury severity levels (categorized by three groups: no injury, minor injury, and severe injury). The six models are the (i) mixed logit severity model for male pedestrians under 50 years old, (ii) mixed logit severity model for female pedestrians under 50 years old, (iii) multinomial logit severity model for male pedestrians 50 years old and older, (iv) multinomial logit severity model for female pedestrians 50 years old and older, (v) latent class multinomial logit severity model for male pedestrians under 50 years old, and (vi) latent class multinomial logit severity model for female pedestrians under 50 years old. To test whether or not the injury severity of pedestrian models is significantly different across age and genders groups, log-likelihood ratio tests were applied.

The findings show that age and gender combination give statistically different effects on resulting injury severities. There are eight variables that have given the effects. They are (i) city streets urban roads, (ii) state numbered urban roads, (iii) failing to yield right-of way, (iv) failing to reduce speed to avoid crash, (v) not-at-intersection indicator, (vi) dry conditions, (vii) no controls, and (viii) local road or street. The results of all models, which include mixed logit models, multinomial logit models, and latent class logit models, show that the injury severity for older males, younger males, older females, and younger females are different. If a collision is on city streets urban roads, and state numbered urban roads, older males and younger males tend to have higher injury severity level relative to older females and younger females. The results also show that older females and younger females do not always have lower injury severity levels relative to older males and younger males. When a primary cause of a crash is failing to yield right-of way and failing to reduce speed to avoid crash, older females and younger females are likely to have more severe injuries relative to older males and younger males. Moreover, when a pedestrian entering/ leaving/ crossing is not at an intersection and if road surface condition is dry, older females are likely to have higher injury severities relative to younger males and younger females. Also, when there is no control device, younger males are more likely to have higher injury severities than younger females. Finally, if a collision occurs in a local road or street, older males tend to have higher severity injuries than younger females.

In conclusion, the overall findings show that older males and older females will be more likely to have higher injury severities than other groups of people in most of significant variables (if a collision occurs on city streets urban roads segment, if a collision occurs on state numbered urban roads segment, if the primary cause of the crash is failing to yield right-of way, if pedestrian entering/ leaving/ crossing is not at intersection, if road surface condition is dry, and if road functional class is local road or urban). These findings suggest that it is better to have a well-design and well-placed crosswalks, a small island in two-way streets, streets narrowing, street ramps, clear road signs, resting places, and wide, and flat sidewalks. These will help mitigate injury severities, especially for older people.

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APPENDIX A: TABLES AND FIGURES OF MARGINAL EFFECTS

Table A.1 Marginal effect for mixed logit severity model results for male pedestrians under 50 years old

Variable	Parameter estimate	t- statistic	Marginal effects		
			No injury	Minor injury	Severe injury
Defined for severe injury					
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-1.841	-6.63	0.0052	0.0117	-0.0170
Darkness (1 if darkness roadway; 0 otherwise)	0.618	2.13	-0.0025	-0.0025	0.0050
Other (1 if pedestrian action is other; 0 otherwise)	0.363	2.07	-0.0045	-0.0045	0.0091
In roadway (1 if pedestrian location is in roadway; 0 otherwise)	0.278	1.95	-0.0089	-0.0091	0.0180
Darkness and lighted (1 if darkness and lighted roadway; 0 otherwise)	0.356	2.31	-0.0070	-0.0070	0.0140
Functioning improperly (1 if traffic control device condition is functioning improperly; 0 otherwise)	1.302	3.07	-0.0025	-0.0028	0.0053
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.676	11.62	-0.1852	0.2679	-0.0827
S*tandard deviation of City streets urban roads (normally distributed)*	1.413	1.59			
Crosswalk not available (1 if pedestrian location is not available crosswalk; 0 otherwise)	0.943	1.51	-0.0015	0.0021	-0.0006
Defined for no injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	2.005	10.34	0.3387	-0.2271	-0.1116
Failing to yield right- of way (1 if the primary cause of the crash is failing to yield right- of way; 0 otherwise)	-0.420	-2.75	-0.0169	0.0115	0.0054
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.123	-2.16	-0.0027	0.0017	0.0010
Not at intersection (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)	-0.610	-2.09	-0.0050	0.0033	0.0017

Table A.1 (Continued)

Intoxicated pedestrian (1 if pedestrian is an intoxicated pedestrian; 0 otherwise)	-0.511	-1.43	-0.0026	0.0017	0.0010
Traffic signal (1 if traffic control device is traffic signal; 0 otherwise)	-0.282	-1.75	-0.0171	0.0119	0.0052
Dry (1 if road surface condition is dry; 0 otherwise)	-0.276	-2.13	-0.0382	0.0259	0.0123
Dusk (1 if dusk roadway; 0 otherwise)	-0.821	-2.08	-0.0035	0.0023	0.0012
No controls (1 if there is no control device; 0 otherwise)	-0.457	-2.88	-0.0447	0.0297	0.0150
Divided without median barrier (1 if collision is on divided without median barrier road segment; 0 otherwise)	-0.189	-1.55	-0.0127	0.0085	0.0041
Model statistics					
Number of observations			1773		
Log likelihood at constant			-1947.84		
Log likelihood at convergence			-1714.47		

Table A.2 Marginal effect for mixed logit severity model results for female pedestrians under 50 years old

Variable	Parameter estimate	t- statistic	Marginal effects		
			No injury	Minor injury	Severe injury
Defined for severe injury					
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-0.832	-2.76	0.0023	0.0061	-0.0085
Traffic signal (1 if traffic control device is traffic signal; 0 otherwise)	0.666	2.98	-0.0165	-0.0146	0.0310
Vision obscured (1 if the primary cause of the crash is vision obscured)	0.788	1.62	-0.0012	-0.0014	0.0026
Operating vehicle in erratic, reckless, careless, negligent or aggressive manner (1 if the primary cause of the crash is operating vehicle in erratic, reckless, careless, negligent or aggressive manner; 0 otherwise)	1.595	2.69	-0.0022	-0.0023	0.0045
Crossing- with signal (1 if pedestrian action is crossing- with signal; 0 otherwise)	-0.450	-2.25	0.0068	0.0060	-0.0128
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-0.441	-1.63	0.0028	0.0031	-0.0059
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.305	6.16	-0.1295	0.1741	-0.0446
S*tandard deviation of City streets urban roads (normally distributed)*	1.727	2.30			
Crosswalk not available (1 if pedestrian location is not available crosswalk; 0 otherwise)	1.433	1.73	-0.0017	0.0024	-0.0007
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.946	-3.31	0.0023	-0.0062	0.0039
Intersection related (1 if collision on intersection; 0 otherwise)	0.437	2.64	-0.0316	0.0447	-0.0131
Divided with median barrier (1 if collision is on divided with median barrier road segment; 0 otherwise)	0.542	1.82	-0.0043	0.0064	-0.0021
Other principal arterial (1 if road functional class is other principal arterial; 0 otherwise)	0.473	2.57	-0.0112	0.0177	-0.0065
Work zone (1 if crash on work zone related road segment; 0 otherwise)	-1.989	-2.31	0.0017	-0.0026	0.0009
Defined for no injury					
No controls (1 if there is no control device; 0 otherwise)	-0.732	-1.83	-0.0068	-0.0017	0.0085
S*tandard deviation of No controls (normally distributed)*	2.243	1.69			
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.487	7.03	0.2100	-0.1443	-0.0658
Failing to yield right- of way (1 if the primary cause of the crash is failing to yield right- of way; 0 otherwise)	-0.401	-2.40	-0.0189	0.0132	0.0057
Disregarding traffic signals (1 if the primary cause of the crash is disregarding traffic signals; 0 otherwise)	-1.469	-2.41	-0.0028	0.0016	0.0012
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	-1.691	-3.31	-0.0054	0.0020	0.0034

Table A.2 (Continued)

Hit and run (1 if hit and run crash; 0 otherwise)	0.327	1.95	0.0165	-0.0117	-0.0048
Model statistics					
Number of observations			1632		
Log likelihood at constant			-1792.94		
Log likelihood at convergence			-1547.28		

Table A.3 Marginal effect for multinomial logit severity model results for male pedestrians 50 years old and older

Variable	Parameter estimate	t- statistic	Marginal effects		
			No injury	Minor injury	Severe injury
Defined for severe injury					
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-1.044	-2.53	0.0418	0.0634	-0.1053
Walking with traffic (1 if pedestrian is walking with traffic; 0 otherwise)	-1.326	-1.79	0.0759	0.1150	-0.1909
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	0.402	1.94	-0.0230	-0.0349	0.0579
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.731	4.24	-0.2695	0.4197	-0.1502
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	1.246	2.73	-0.1940	0.3022	-0.1082
Straight (1 if roadway alignment is straight and level; 0 otherwise)	-0.731	-1.84	0.1138	-0.1772	0.0634
Defined for no injury					
Older (1 if pedestrian is olderer than 70 years older; 0 otherwise)	0.578	3.25	0.1230	-0.0899	-0.0331
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	0.785	3.56	0.1671	-0.1222	-0.0449
Darkness and lighted (1 if darkness and lighted roadway; 0 otherwise)	-0.461	-2.34	-0.0981	0.0718	0.0264
Clear (1 if the weather is clear; 0 otherwise)	-0.308	-1.67	-0.0655	0.0479	0.0176
Stand (1 if pedestrian is standing in roadway; 0 otherwise)	-0.613	-1.68	-0.1304	0.0954	0.0351
One- way or ramp (1 if collision is on one- way or ramp road segment; 0 otherwise)	0.440	1.78	-0.1304	0.0954	0.0351
Collector (1 if road functional class is collector (urban); 0 otherwise)	0.295	1.60	-0.1304	0.0954	0.0351
Model statistics					
Number of observations			705		
Log likelihood at constant			-727.33		
Log likelihood at convergence			-697.58		

Table A.4 Marginal effect for multinomial logit severity model results for female pedestrians 50 years old and older

Variable	Parameter estimate	t- statistic	Marginal effects		
			No injury	Minor injury	Severe injury
Defined for severe injury					
Older (1 if pedestrian is olderer than 70 years older; 0 otherwise)	0.732	3.09	-0.0449	-0.0619	0.1068
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-1.903	-3.85	0.1167	0.1610	-0.2777
Not at intersection (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)	0.741	1.91	-0.0454	-0.0627	0.1081
Dry (1 if road surface condition is dry; 0 otherwise)	0.463	1.74	-0.0284	-0.0391	0.0675
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	0.388	1.83	-0.0238	-0.0329	0.0567
Defined for minor injury					
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.542	5.50	-0.2345	0.3649	-0.1304
Crossing- against signal (1 if pedestrian action is crossing- against signal; 0 otherwise)	0.913	2.82	-0.1388	0.2161	-0.0772
Other (1 if pedestrian action is other; 0 otherwise)	0.639	2.69	-0.0972	0.1512	-0.0540
Walking against traffic (1 if pedestrian is walking against traffic; 0 otherwise)	0.709	1.97	-0.1079	0.1679	-0.0600
Defined for no injury					
Older (1 if pedestrian is olderer than 70 years older; 0 otherwise)	0.498	2.52	0.1062	-0.0757	-0.0305
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	1.631	5.23	0.3480	-0.2480	-0.1000
Functioning properly (1 if traffic control device condition is functioning properly; 0 otherwise)	-0.160	-1.73	-0.0342	0.0244	0.0098
Walking with traffic (1 if pedestrian is walking with traffic; 0 otherwise)	-0.620	-1.57	-0.1341	0.0956	0.0385
Crosswalk (1 if pedestrian location is in crosswalk; 0 otherwise)	-0.317	-1.66	-0.0676	0.0482	0.0194
Unable to determine (1 if the primary cause of the crash is unable to determine; 0 otherwise)	0.360	1.86	0.0769	-0.0548	-0.0221
Divided without median barrier (1 if collision is on divided without median barrier road segment; 0 otherwise)	-0.271	-1.56	-0.0578	0.0412	0.0166
Model statistics					
Number of observations			649		
Log likelihood at constant			-670.46		
Log likelihood at convergence			-642.25		

Table A.5 Marginal effect for latent class multinomial logit severity model results for male pedestrians under 50 years old

Variable	Latent class 1		Latent class 2		Marginal effects		
	Parameter estimate	t-statistic	Parameter estimate	t-statistic	No injury	Minor injury	Severe injury
Defined for severe injury							
State numbered urban roads (1 if collision on state numbered urban roads segment; 0 otherwise)	-0.555	-0.88	-1.946	-3.70	0.0066	0.0045	-0.0111
In roadway (1 if pedestrian location is in roadway; 0 otherwise)	-2.863	-2.44	0.806	3.00	-0.0332	0.0076	0.0256
Functioning improperly (1 if traffic control device condition is functioning improperly; 0 otherwise)	-3.399	-0.24	1.751	2.76	-0.0034	-0.0005	0.0038
Defined for minor injury							
Weekend (1 if crash occurred during weekend; 0 otherwise)	2.457	2.82	-2.227	-1.16	-0.0018	0.0090	-0.0088
Failing to yield right-of way (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)	2.106	2.65	-0.264	-0.32	-0.0018	0.0101	-0.0083
Vision obscured (1 if the primary cause of the crash is vision obscured)	-0.042	-0.04	2.292	1.66	-0.0025	0.0034	-0.0008
One- way or ramp (1 if collision is on one- way or ramp road segment; 0 otherwise)	1.512	1.71	-14.211	-0.01	-0.0018	0.0051	-0.0033
Defined for no injury							
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	-0.847	-1.48	1.425	4.62	0.1102	-0.0141	-0.0961
Dry (1 if road surface condition is dry; 0 otherwise)	-1.216	-1.90	-0.265	-1.04	-0.0399	0.0213	-0.0186
Daylight (1 if daylight; 0 otherwise)	-0.269	-0.43	0.422	1.95	0.0195	-0.0033	-0.0162
Failing to reduce speed to avoid crash (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)	1.283	1.04	-2.087	-1.71	-0.0009	-0.0005	0.0014
Other principal arterial (1 if road functional class is other principal arterial; 0 otherwise)	0.695	1.10	-0.654	-2.07	-0.0062	-0.0004	0.0066
Class probability	0.532	18.26	0.468	16.09			
Model statistics							
Number of observations			1773				
Log likelihood at convergence			-1771.00				
Restricted log-likelihood			-1947.84				

Table A.6 Marginal effect for latent class multinomial logit severity model results for female pedestrians under 50 years old

Variable	Latent class 1		Latent class 2		Marginal effects		
	Parameter estimate	t-statistic	Parameter estimate	t-statistic	No injury	Minor injury	Severe injury
Defined for severe injury							
Local road or street (1 if road functional class is local road or street (urban); 0 otherwise)	-1.271	-3.02	-0.142	-0.28	0.0019	0.0099	-0.0119
Not at intersection (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)	-1.915	-0.95	1.869	1.97	-0.0064	0.0018	0.0046
Unable to determine (1 if the primary cause of the crash is unable to determine; 0 otherwise)	-0.613	-1.96	-0.951	-1.84	0.0073	0.0086	-0.0159
Defined for minor injury							
Intersection related (1 if collision on intersection; 0 otherwise)	1.749	4.51	-0.427	-0.43	-0.0298	0.0744	-0.0446
Crossing- against signal (1 if pedestrian action is crossing- against signal; 0 otherwise)	2.360	1.56	-1.846	-0.65	0.0000	0.0026	-0.0025
Hit and run (1 if hit and run crash; 0 otherwise)	0.694	2.32	-3.816	-0.22	-0.0044	0.0148	-0.0104
Divided with median barrier (1 if collision is on divided with median barrier road segment; 0 otherwise)	0.408	0.52	1.771	1.93	-0.0077	0.0111	-0.0033
Defined for no injury							
City streets urban roads (1 if collision on city streets urban roads segment; 0 otherwise)	-0.431	-0.91	1.385	3.81	0.0652	-0.0165	-0.0487
Walking against traffic (1 if pedestrian is walking against traffic; 0 otherwise)	2.686	2.69	-2.017	-2.07	0.0072	-0.0092	0.0020
No controls (1 if there is no control device; 0 otherwise)	-2.378	-1.80	0.914	1.43	-0.0016	0.0075	-0.0059
Class probability	0.594	11.38	0.406	7.77			
Model statistics							
Number of observations			1632				
Log likelihood at convergence			-1578.76				
Restricted log-likelihood			-1792.94				

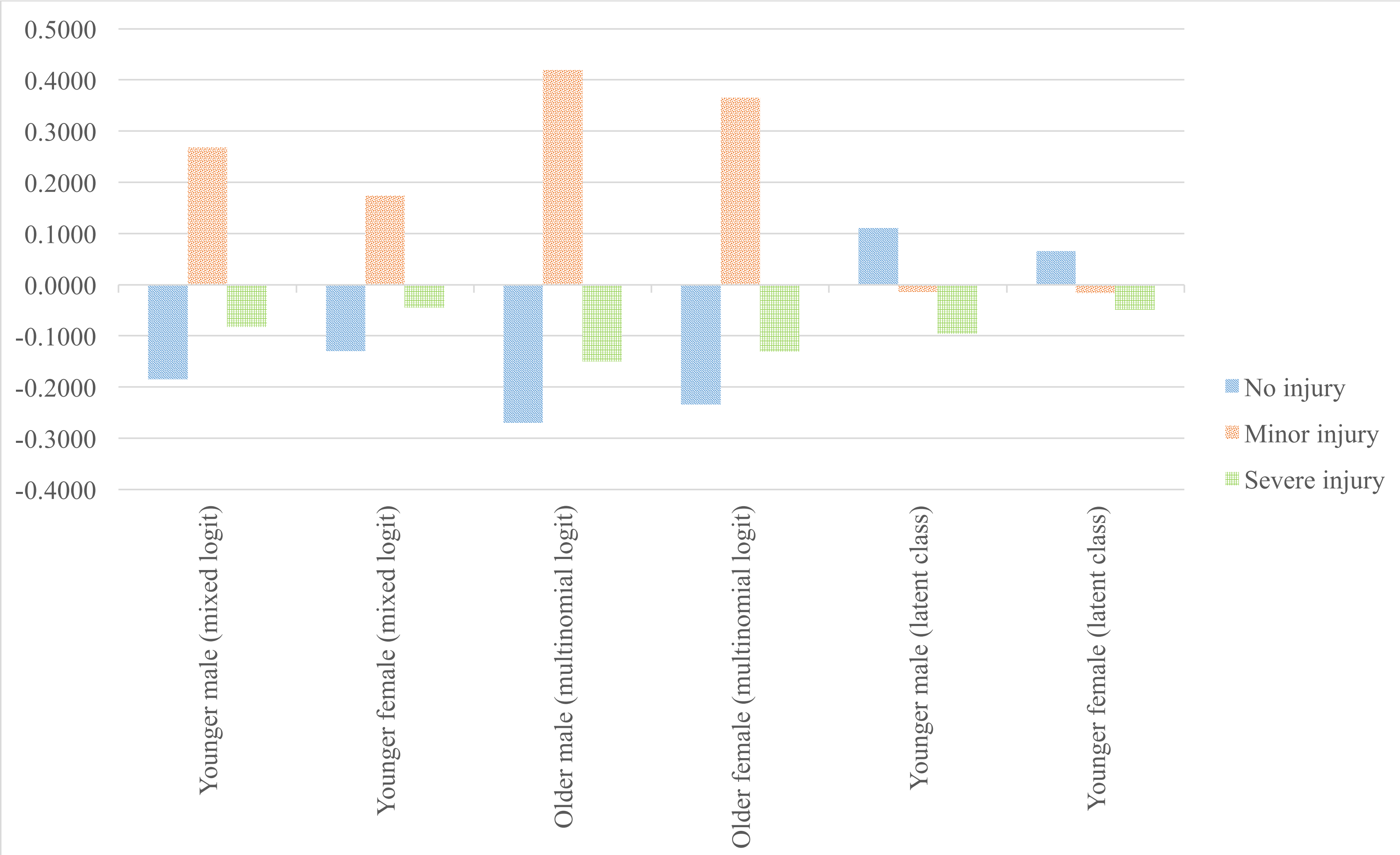

Figure A.1a Marginal effects for "City streets urban roads" when it is defined for minor injury level (1 if collision on city streets urban roads segment; 0 otherwise)

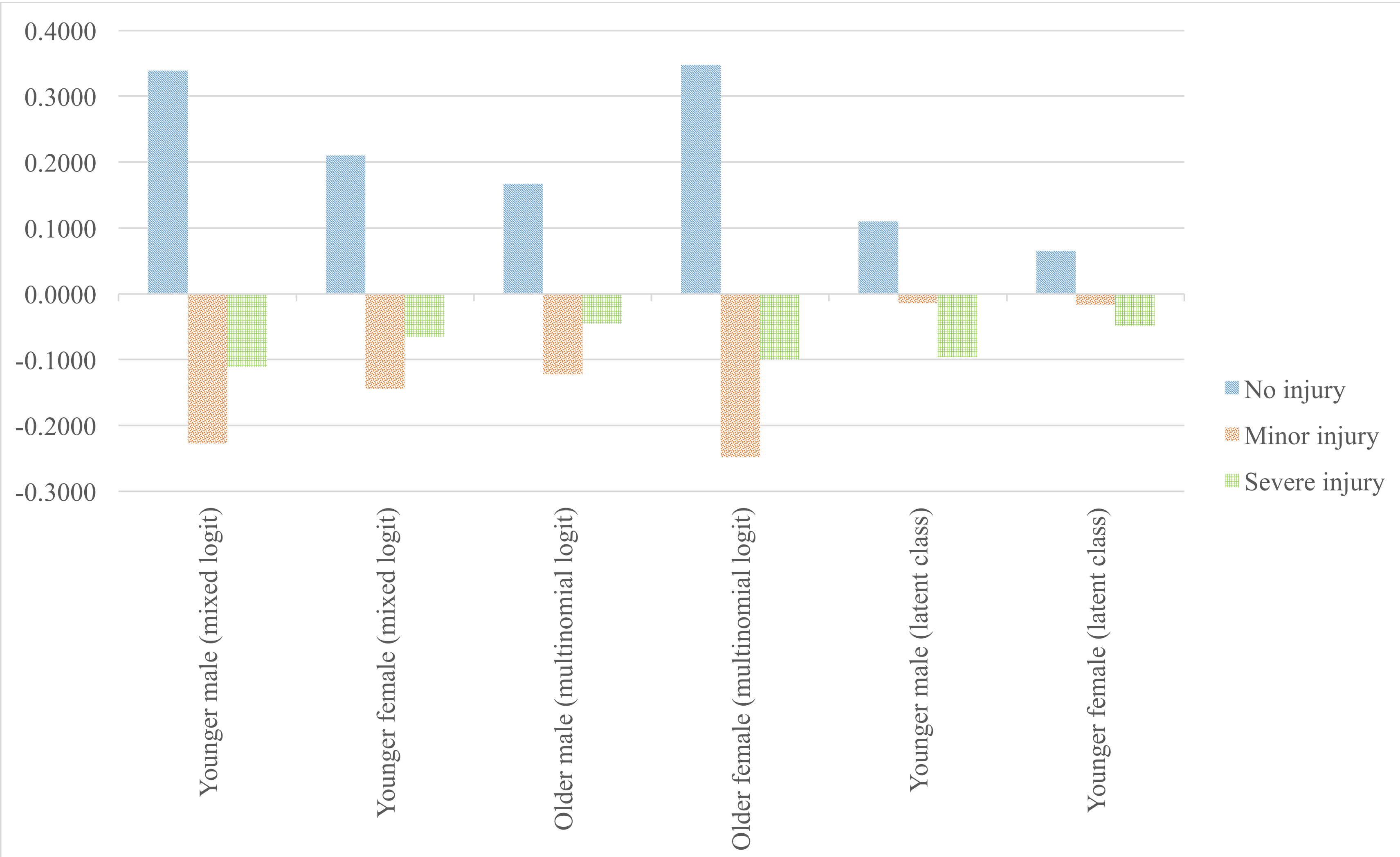

Figure A.1b Marginal effects for "City streets urban roads" when it is defined for no injury level (1 if collision on city streets urban roads segment; 0 otherwise)

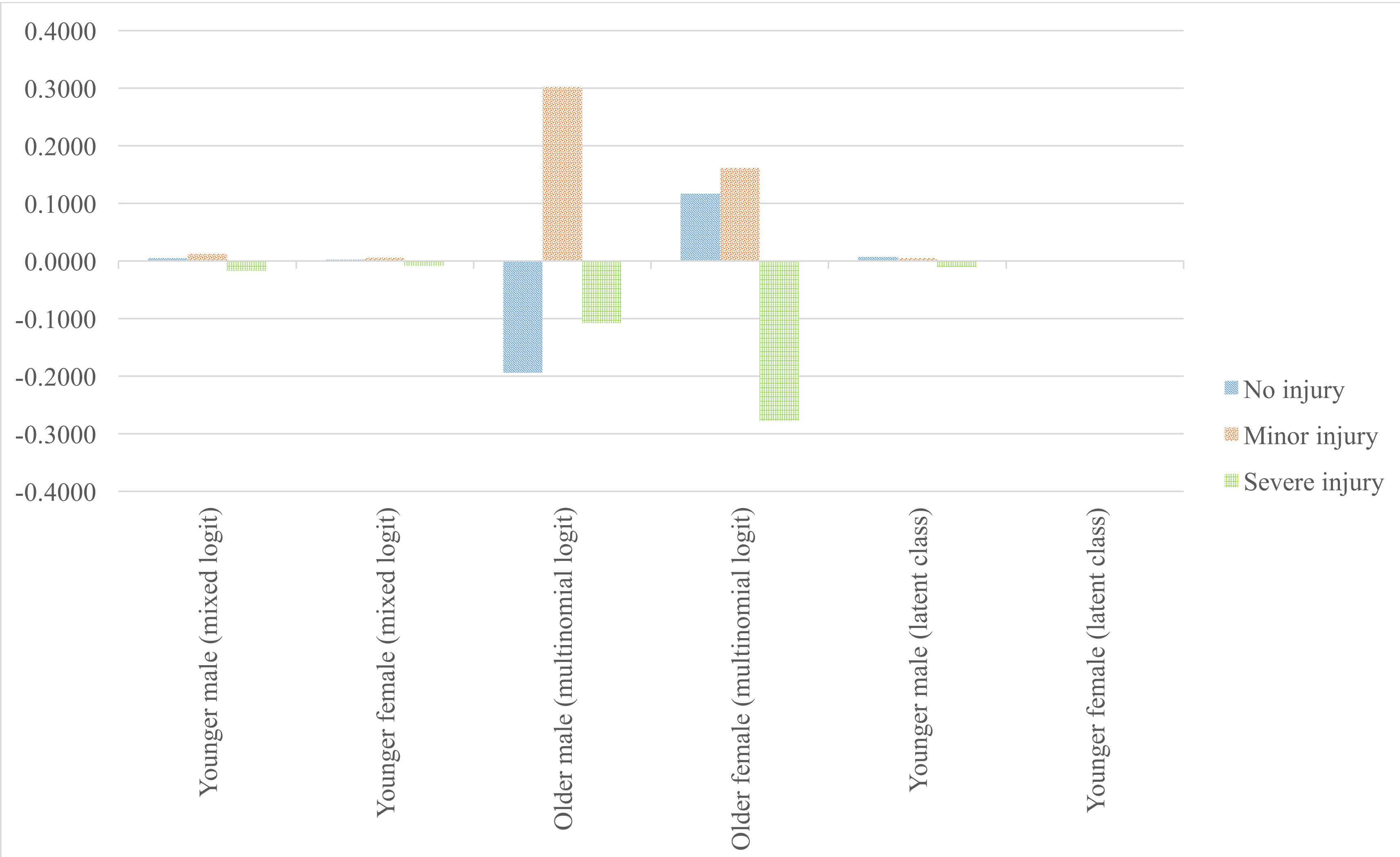

Figure A.2 Marginal effects for “State numbered urban roads” (1 if collision on state numbered urban roads segment; 0 otherwise)

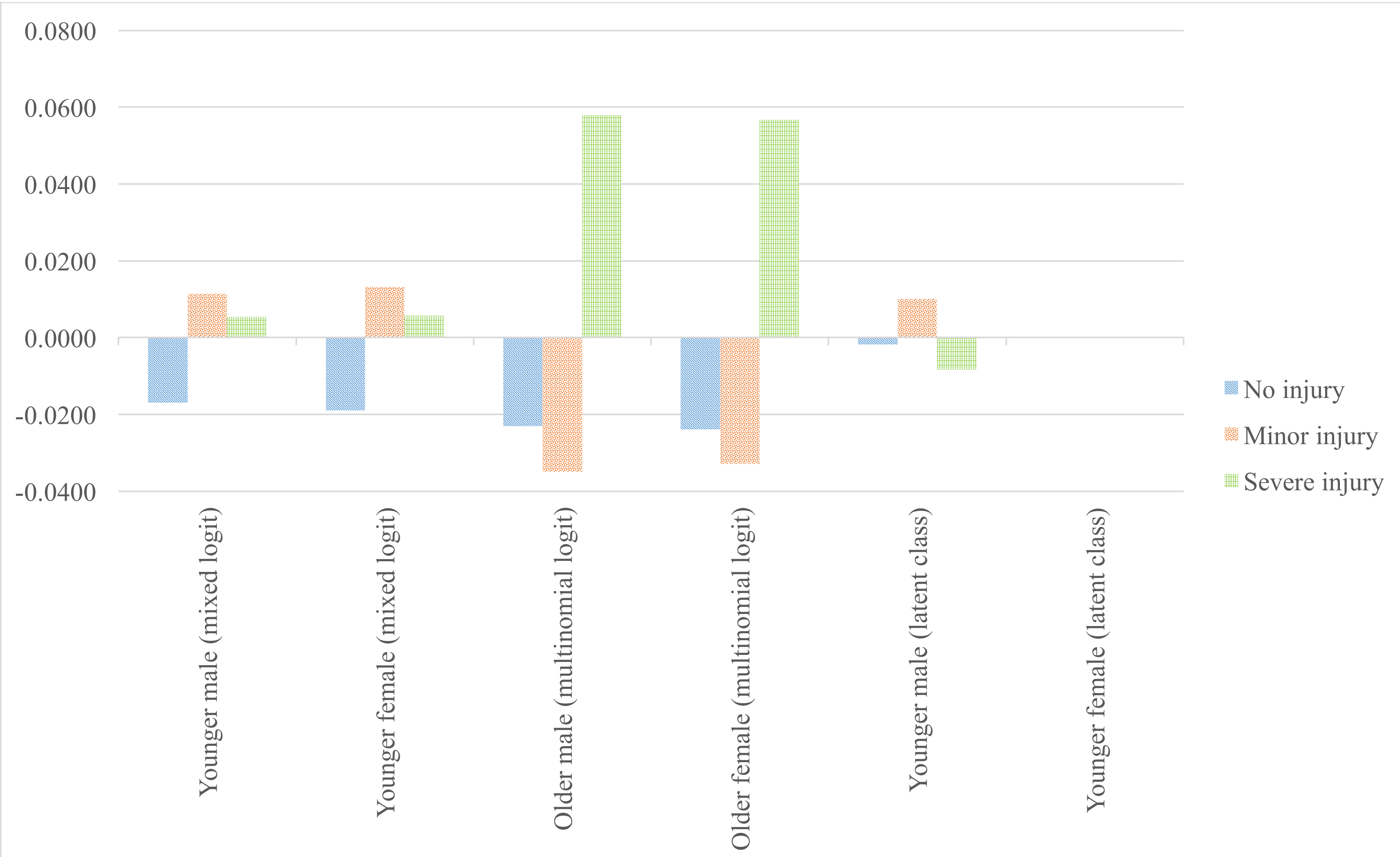

Figure A.3 Marginal effects for “Failing to yield right-of way” (1 if the primary cause of the crash is failing to yield right-of way; 0 otherwise)

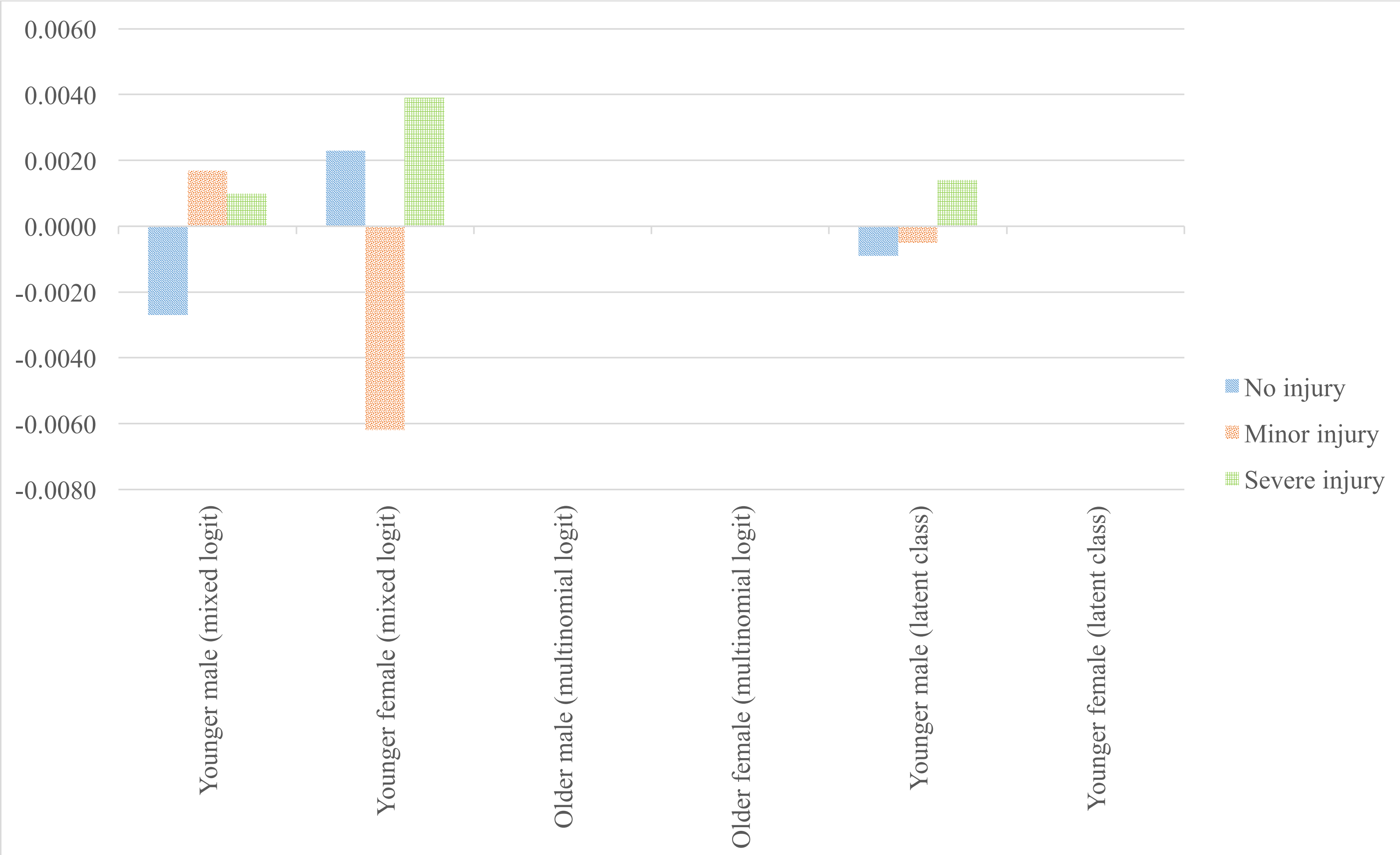

Figure A.4 Marginal effects for “Failing to reduce speed to avoid crash” (1 if the primary cause of the crash is failing to reduce speed to avoid crash; 0 otherwise)

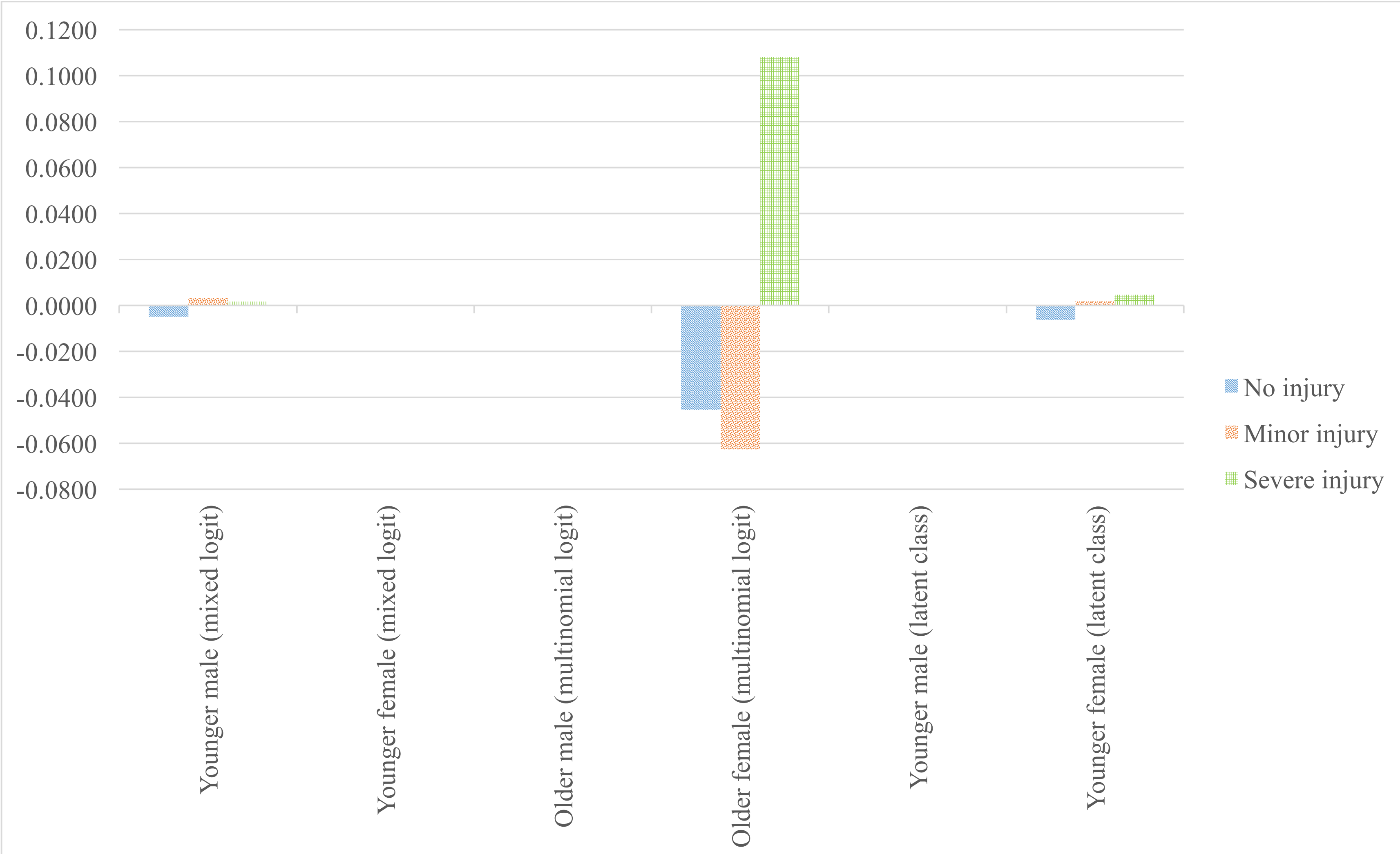

Figure A.5 Marginal effects for “Not at intersection” (1 if pedestrian entering/ leaving/ crossing is not at intersection; 0 otherwise)

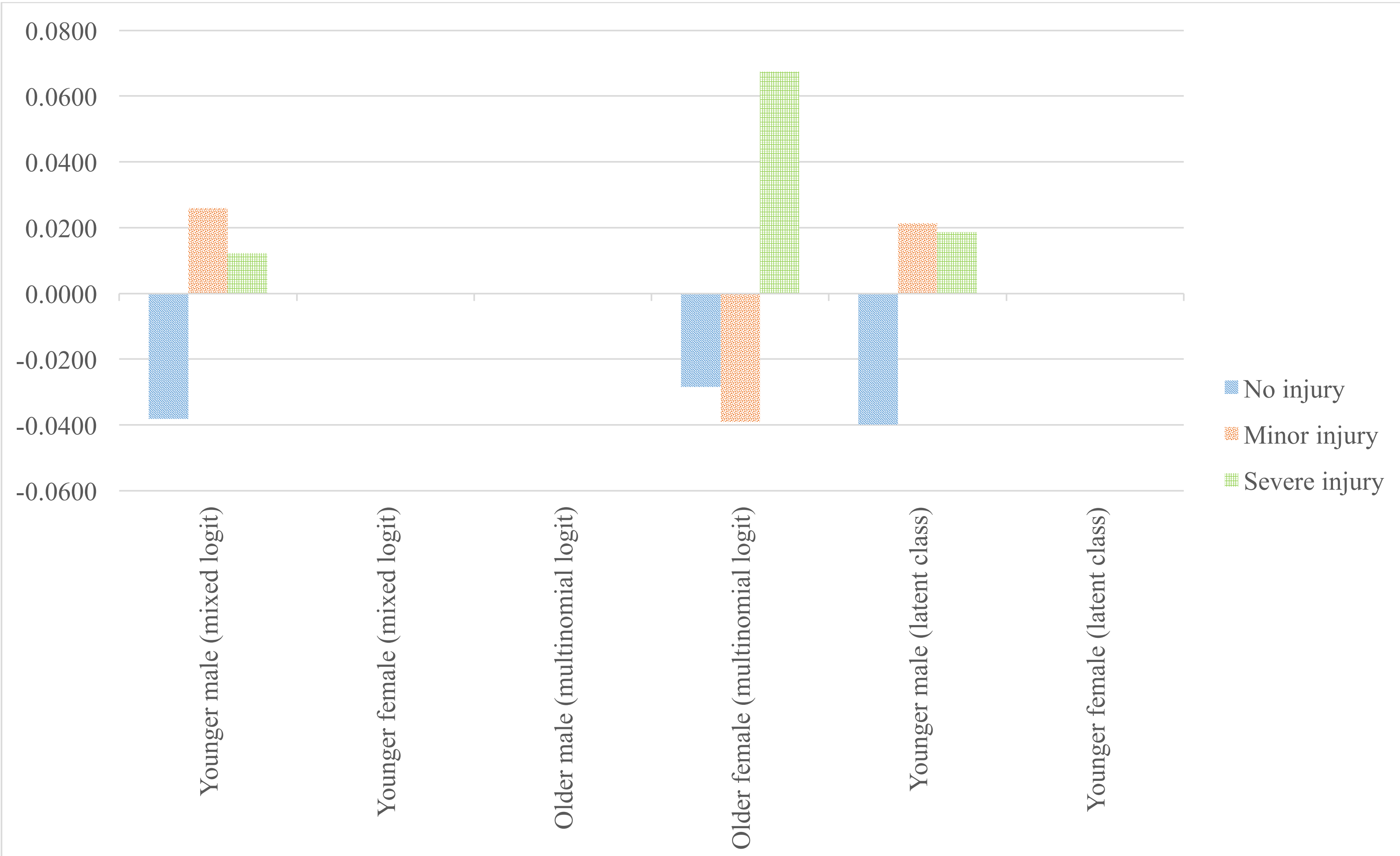

Figure A.6 Marginal effects for "Dry" (1 if road surface condition is dry; 0 otherwise)

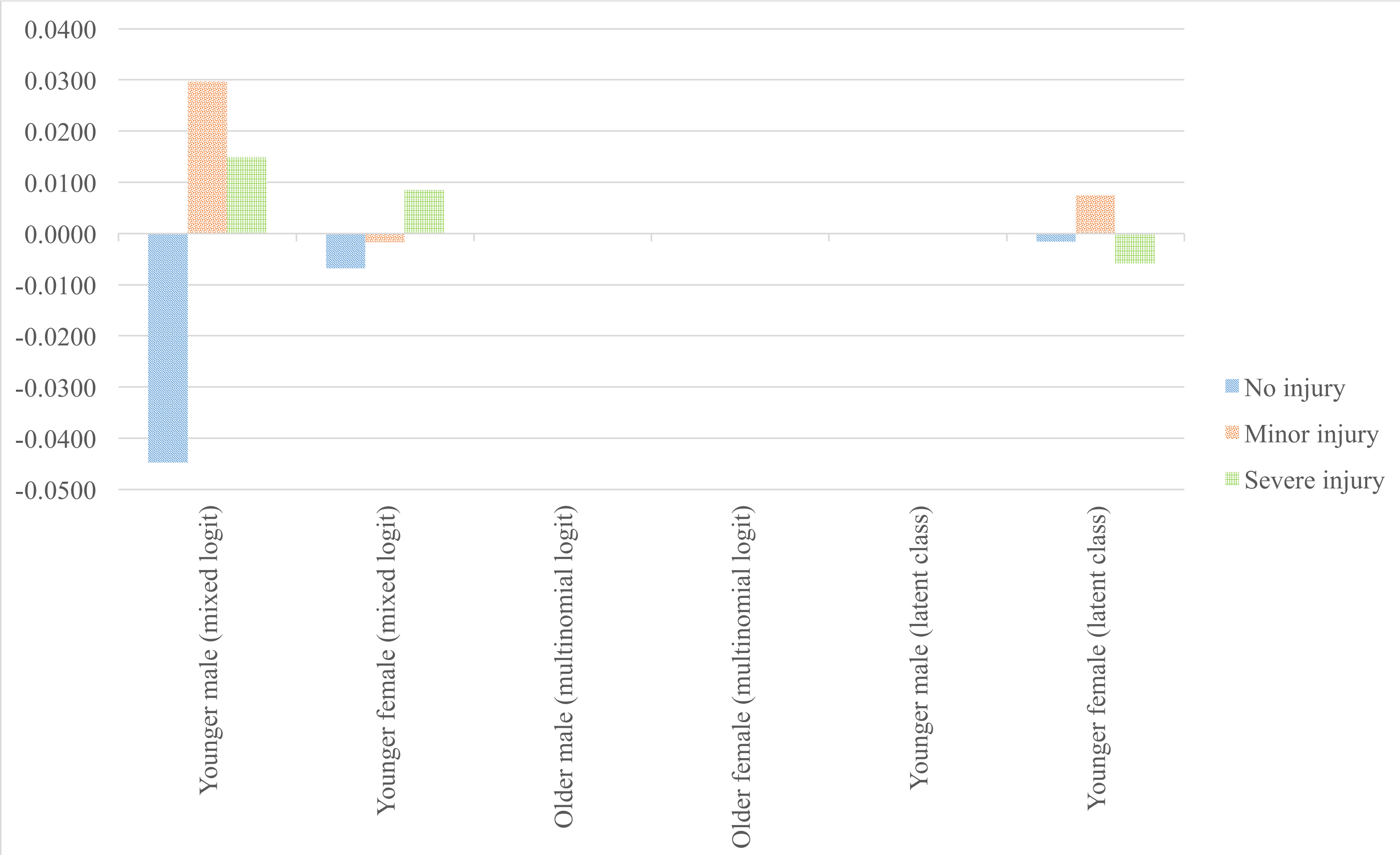

Figure A.7 Marginal effects for “No controls” (1 if there is no control device; 0 otherwise)

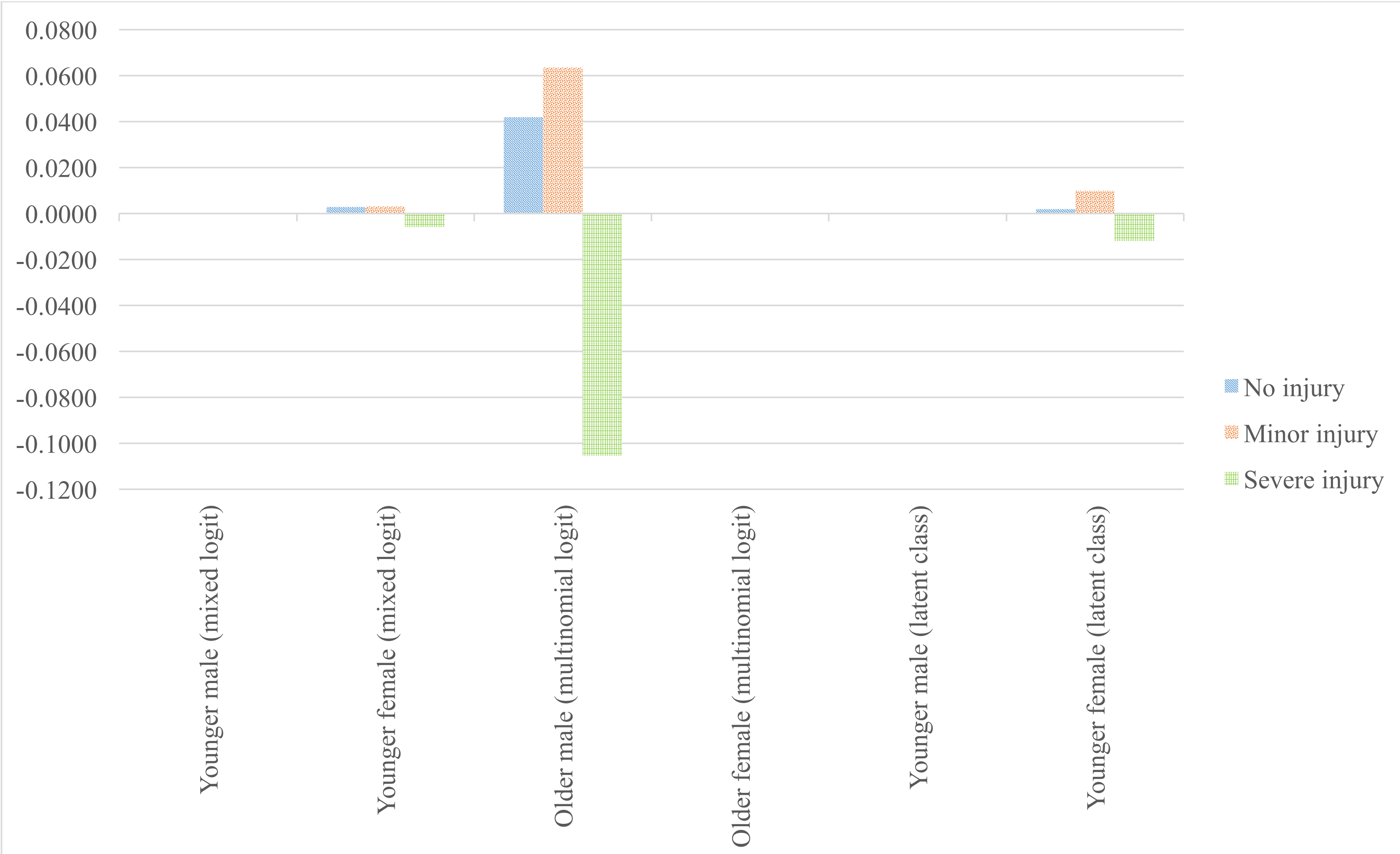

Figure A.8 Marginal effects for "Local road or street" (1 if road functional class is local road or street (urban); 0 otherwise)