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# The effect of crash characteristics on cyclist injuries: An analysis of Virginia automobile-bicycle crash data

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ABSTRACT

This paper examines bicyclist, automobile driver, vehicle, environmental, and roadway characteristics that influence cyclist injury severity in order to determine which factors should be addressed to mitigate the worst bicyclist injuries. An ordered probit model is used to examine single bicycle-single vehicle crashes from Virginia police crash report data from 2010 to 2014. Five injury severity levels are considered: fatalities, severe injuries, minor or possible injuries, no apparent injuries, and no injury. The results of this study most notably found automobile driver intoxication to increase the probability of a cyclist fatality six fold and double the risk of a severe injury, while bicyclist intoxication increases the probability of a fatality by 36.7% and doubles the probability of severe injury. Additionally, bicycle and automobile speeds, obscured automobile driver vision, specific vehicle body types (SUV, truck, and van), vertical roadway grades and horizontal curves elevate the probability of more severe bicyclist injuries. Model results encourage consideration of methods to reduce the impact of biking and driving while intoxicated such as analysis of bicycling under the influence laws, education of drunk driving impacts on bicyclists, and separation of vehicles and bicycles on the road. Additionally, the results encourage consideration of methods to improve visibility of bicyclists and expectation of their presence on the road.

## 1. Introduction

Over the past two decades, fatality rates associated with automobile crashes have declined nationally in the United States. During this same time, the absolute number of bicyclist fatalities has also declined. However, bicyclist fatalities as a percentage of total transportation-related deaths (automobile, motorcycle, pedestrian, and cyclist) have increased, representing a slower decline in mitigating bicyclist fatalities as compared to other transportation modes (FARS, 2016). Meanwhile, the rate of bicycling in the United States is on the rise. Nationwide modal share of bike commuters rose 67% between 2005 and 2015, an increase of approximately 357,600 bike commuters (U.S. Census Bureau, 2015). This percentage increase is even higher in Virginia, where bike commuters increased 128% in the same time period, by approximately 9260 commuters (U.S. Census Bureau, 2015). As cities, counties, and departments of transportation invest more resources into bicycle infrastructure and bicycling rates continue to grow, it must be understood what can be done to minimize the crash risk of vulnerable bicyclists. Between 2010 and 2014, 3679 crashes between bicyclists and automobiles were reported in Virginia. Forty nine of those crashes resulted in a fatality. These statistics highlight the need to understand the causes behind the most severe and deadly bicycle and automobile collisions in order to mitigate dangerous crashes in the future. This research analyzes Virginia bicycle and automobile crash data to identify the factors which contribute to injury severity of bicyclists in bicycle-automobile crashes.

## 2. Previous literature

Previous studies have identified many possible factors contributing to crashes between bicycles and automobiles, including infrastructure, environmental, and temporal factors, as well as driver, vehicle, and roadway characteristics. Reynolds et al. (2009) reviewed 23 papers that examined the effect of transportation infrastructure on bicyclist crashes and injury, concluding that bicycle-specific facilities such as bike routes, bike lanes, and off road bike paths reduce cyclist crashes and injury. Bicycle-specific facilities are in contrast with multi-use roads where bikes share motor vehicle lanes or travel on sidewalks. Additionally, bicyclist safety was shown to improve with street lighting, paved surfaces, and low angle grades (Reynolds et al., 2009).

In addition to transportation facility and environmental factors, human factors also contribute to bicycle and automobile crashes. Lack

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of attention from bicyclists and automobile drivers about their surroundings, as well as unclear expectations about the behavior of other cars and bikes on the road, leads to bicycle and automobile crashes. For example, Rasanen and Summala (1997) conclude that the most common bicycle-car collision results when the driver looks left for oncoming vehicles when they should also be looking right for cyclists. This lack of driver expectation about where bicyclists will be and how they will behave increases the occurrence of bicycle-automobile crashes.

Other studies have focused on factors that specifically affect injury severity in bicycle and automobile crashes. Identifying factors that contribute to the most severe bicyclist injuries can motivate policy and infrastructure changes to prevent the most debilitating of crashes. Previous studies have shown that temporal and environmental characteristics can influence injury severity. By cycling at night, the likelihood of a severe bicyclist crash increases (Eluru et al., 2008; Rodgers, 1995). Eluru et al. (2008) found that riding between midnight and 6 a.m. increases the probability of a fatal accident by almost five-fold compared to daytime (6 a.m.–6 p.m.) riding. Night time riding is particularly dangerous in areas without streetlights (Yan et al., 2011; Kim et al., 2007; Klop and Khattak, 1999). Kim et al. (2007) identified cycling at night without streetlights as a crash injury risk, increasing the probability of a fatal injury by 110.9% compared to crashes occurring in daytime or in areas with streetlights. Similarly, fog leads to a reduction in visibility and has been shown to be a risk factor for increased injury severity (Klop and Khattak, 1999). More broadly, inclement weather has been identified as a factor in doubling the risk of a fatal cyclist injury (Kim et al., 2007).

Cyclist characteristics, such as age, gender, and alcohol consumption, are also risk factors for increased cyclist injury severity. Numerous studies have cited old age as a risk factor (Yan et al., 2011; Moore et al., 2011; Eluru et al., 2008). Kim et al. (2007) specifically describe cyclists over the age of 55 as a factor that could double the risk of a fatality. Similarly, Rodgers (1995) concludes that cyclists older than 44 are at a greater risk for a fatality and Eluru et al. (2008) found that cyclists over age 60 are more than four times more likely to be fatally injured compared to cyclists younger than 60. Rodgers (1995) also found that males have a five times greater risk of being killed in a bike crash compared to females, when adjusted for exposure. Alcohol consumption has also been shown to increase severe injuries. Sethi et al. (2016) found that alcohol use in urban bicyclists was inversely correlated with helmet use and associated with more severe injuries and greater mortalities. Andersson and Bunketorp (2002) found that intoxicated cyclists less often wore helmets and were at a greater risk of head and face injuries. Specifically, Moore et al. (2011) found that when the automobile driver was under the influence of alcohol, the likelihood of a severe injury increased by 82.2% if the crash occurred at an intersection and 150.1% at a non-intersection location. Kim et al. (2007) also found the probability of a fatal injury to more than double if either the cyclist or the driver in a crash were intoxicated.

Automobile characteristics such as speed of the automobile, type of automobile, and angle at which the automobile collided with the bicycle have also been shown to affect injury severity. In several studies, high vehicle speed at the time of collision increased likelihood of a severe injury. The exact speed which constitutes a high speed is not consistent in all studies, with most studies simply concluding higher speeds lead to more dangerous crashes (Eluru et al., 2008; Yan et al., 2011; Moore et al., 2011). Kim et al. (2007) specifically identify speeds above 30 mph to double the probability for a fatality, and that speeds above 50 mph increase the risk of fatality by 16 fold. Eluru et al. (2008) found that speeds above 50 mph increase fatality risks by 470.81%. Additionally, if the vehicle involved in the accident is a heavy-duty vehicle, injury severity risk also increases (Yan et al., 2011; Kim et al., 2007; Moore et al., 2011). Kim et al. (2007) find that in bicycle collisions with heavy trucks, the probability of a fatality increases by 390.9% and the probability of an incapacitating injury increase by 101.8%. Furthermore, head-on (Yan et al., 2011; Kim et al., 2007) and single collisions (Yan et al., 2011; Moore et al., 2011) were shown to increase injury severity. Kim et al. (2007) found that head-on collisions double the probability of a fatal injury.

Lastly, roadway characteristics have also been shown to affect injury severity levels. Kim et al. (2007) found that divided roads increase non-incapacitating injuries by 13.5%. Yan et al. (2011) found that fewer bicyclists rode against traffic when there was a median, which was previously hypothesized by Kim et al. (2007) as a reason for reduced injury severity on divided roads. Klop and Khattak (1999) discuss grades on straight and curved roads as being detrimental to bike safety. Additionally, Moore et al., (2011) found horizontal curves with grades in intersections and horizontal and vertical curves at non-intersection locations to increase injury severity. Eluru et al., (2008) also found that crashes at signalized intersections were less severe than at other locations, reducing the probability of a fatal crash by almost 90%. This research aims to corroborate previous findings about factors that increase injury severity and uncover new findings using a Virginia-based crash dataset.

## 3. Data

The data analyzed come from Virginia police crash reports collected between 2010 and 2014 across the entire state. The Virginia Department of Motor Vehicles (VA DMV) provided information for 3679 reported crashes involving a bicyclist. The data include characteristics about the crash, roadway, environment, vehicles (bikes and automobiles), and drivers (cyclists and automobile drivers).

The characteristics defined in the dataset are studied in this research for their effect on cyclist injury severity and therefore these injury severity outcomes are defined explicitly. The Virginia Police Crash Reporting Manual categorizes injury outcomes as fatal, severe injury, minor/possible injury, no apparent injury, and no injury. The bicyclist injury category is determined at the discretion of the police officer (provided manual guidelines) at the scene of the crash. Fatalities include all injuries that result in death within 30 days of the accident. Severe injuries include severe lacerations, broken or distorted limbs, crush injuries, significant burns, unconsciousness or paralysis. Minor or possible injuries include visible injuries such as bruises, abrasions, swelling or limping. No apparent injury is cited when there is no visible injury but the person complains of pain or becomes briefly unconscious. No injury is recorded when by the officer's best judgement, no injury has occurred (VA DMV, 2015). This method of injury severity collection is open to subjectivity on the part of the police officer, and this type of data assessment is discussed in more depth in the section on limitations of the study.

While all the crashes in the VA DMV dataset involve bicyclists, they do not all involve the same number of bicyclists and automobiles. For the purpose of this research (due to limited sample size of other crash types), only crashes between one automobile and one bicycle are included. 3545 (96.4%) of the original VA DMV dataset are single automobile and bike crashes. The removed crash observations include 46 single bicycle crashes (where no automobile was identified), 37 multiple bike crashes (32 involving two bikes and 5 involving three or more bikes), and 51 crashes involving multiple automobiles. The purpose of this exclusion is to focus directly on the dynamic between a single automobile and a single bicycle. Including other automobiles or bicycles confounds the physics and interpretation of the crash, where the main event may be the automobiles hitting each other, or the bicycles crashing into each other instead of the interaction between the car and bike. Furthermore, this study does not assess other common types of crashes, such as single bicycle crashes where no automobile is involved. Due to the automobile-focused nature of the police crash reports, single bicycle crashes (with no automobile involved) are not data that are readily captured in this statewide dataset.

These 3545 crashes have been plotted using latitude and longitude