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Determinants of pedestrian and bicyclist crash severity by party at fault in San Francisco, CA

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ABSTRACT

Pedestrian and bicyclist safety is of growing concern, especially given the increasing numbers of urban residents choosing to walk and bike. Sharing the roads with automobiles, these road users are particularly vulnerable. An intuitive conceptual model is proposed of the determinants of injury severity in crashes between vehicles and nonmotorized road users. Using 10 years of crash data from San Francisco, CA, we estimate logistic regression models to illuminate key determinants of crash severity for both pedestrian and bicyclist collisions. The analyses are separated by party at fault to test the novel hypothesis that environmental factors affecting driver speed and reaction time may be especially important when the driver is not at fault. Pedestrian results are broadly consistent with prior research, and offer considerable support for this hypothesis. The strongest predictors of injury severity include pedestrian advanced age, driver sobriety, vehicle type, and a set of variables that help determine driver speed and reaction time. Bicyclist results were weaker overall, and the distinction by party at fault was less important.

1. Introduction

Increasingly, communities around the world have begun to acknowledge the benefits of having more diversified transportation systems that enable walking and bicycling. Safety is a substantial barrier to active transportation choices, however. Studies examining nonmotorist vulnerability have found that per kilometer traveled, pedestrians are 23 times and bicyclists are 12 times more likely to be killed in traffic accidents than car occupants (Pucher and Dijkstra, 2003). Safety concerns—real and perceived—are cited as a key reason that many choose not to walk or bicycle (e.g., Jacobsen et al., 2009; Loukaitou-Sideris, 2006).

There are two ways that pedestrian and bicyclist safety can be enhanced. The risk of collision can fall, or the severity of collisions can fall. This study focuses on the latter of these safety components, identifying the factors influencing the *severity* of each collision, given that the collision has occurred.

A substantial literature aims to identify the most important determinants of pedestrian and bicyclist injury severity in on-street collisions. The results vary, in part due to differences in study area geography and road users considered. Rural and urban areas have significantly different demographics and built environment characteristics that influence which factors are important in determining injury severity. Some studies sought to identify these differences (Klop and Khattak, 1999; Islam and Jones, 2014; Pour-Rouholamin and Zhou, 2016), while others focused on only rural (Zajac and Ivan, 2003) or only urban areas (e.g., Sze and Wong, 2007; Aziz et al., 2013). Most prior work focused on either pedestrians or bicyclists, while a few studies analyzed both pedestrian and bicyclist crashes (Eluru et al., 2008; Chong et al., 2010; Kröyer, 2015).

Still, certain factors have repeatedly been found to significantly influence bicyclist and pedestrian injury severity levels. When included as predictors, darkness, late night hours, the involvement of alcohol, advanced age of the victim, higher speed limits, culpability of the pedestrian or bicyclist, and large vehicle involvement have all been found to increase severity levels for both pedestrians and bicyclists. Results regarding inclement weather, bicyclist and pedestrian gender, bicycle lanes, intersections, and bicyclist helmet use, on the other hand, have seen mixed results.

This paper expands on the current knowledge regarding the determinants of injury severity for pedestrians and bicyclists, using disaggregate data on individual crashes from the city of San Francisco. We contribute to the literature in four ways. First, we report new results for San Francisco, a city that reflects a wide range of built environment and demographic characteristics, and has one of the highest rates of walking and bicycling among cities in the United States. Second, we estimate the

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determinants of injury severity for both pedestrian and bicyclist crashes using parallel data and methods. This allows us to compare the most important factors influencing crash severity across nonmotorized road user types. Third, we introduce an intuitive conceptual model of injury severity in pedestrian and bicyclist crashes, providing a clear set of hypotheses about how and why key factors affect the severity of a crash. Finally, we focus on identifying whether the factors associated with injury severity differ depending on the party at fault in a crash. This is not an entirely novel idea – Savolainen and Mannering (2007) explore this possibility in a study of motorcycle crashes – but it has not often been tested. In studies of pedestrian and bicyclist crashes, others have modeled party at fault as the dependent variable (Lee and Abdel-Aty, 2005; Kim et al., 2008b; Ulfarsson et al., 2010; Zhang et al., 2014), included party at fault as an explanatory variable in models of injury severity (Kim et al., 2008a; Zhang et al., 2014; Haleem et al., 2015), and focused only on those crashes that were the fault of the nonmotorized road user (Islam and Jones, 2014). To our knowledge, however, this is the first study to investigate whether the determinants of pedestrian and bicyclist crash severity actually depend on whether a crash was the fault of the driver or the nonmotorized road user.

2. Context and data

San Francisco is an ideal location to study the effects of a diverse set of factors on injury severity for pedestrians and bicyclists. San Francisco is also known as one of the most pedestrian-friendly cities in the country. The city's "Walk Score" (a widely used metric to determine city walkability levels) is 85.7 out of 100, second only to New York City in the United States (Musiker, 2016). In 2014, 23% of all trips and 9.9% of commuting trips were on foot in San Francisco (Walk San Francisco, 2017; United States Census, 2015). Despite – or perhaps because of – these high numbers, pedestrians are disproportionately susceptible to involvement in serious accidents. 59% of those killed in traffic collisions in 2014 were pedestrians in San Francisco, compared to the national average of 14% (Vision Zero Coalition, 2015).

Bicycling is increasingly popular in San Francisco as well. Bicycle counts at 19 intersections in San Francisco have seen a 184% increase between 2006 and 2015, and from 2014 to 2015 alone, the number of weekday bicycle trips increased by 8.5% (SFMTA, 2016). In tandem with this increase in bicycling, the city has invested in bicycle infrastructure, particularly in areas with large numbers of bicyclists. Between 2010 and 2014, San Francisco improved bicycle infrastructure on 161 lane miles of road (37% of its bike network) (SFMTA, 2016).

To investigate factors related to injury severity in pedestrian and bicyclist crashes, this study uses detailed collision data for the city of San Francisco from California Highway Patrol's Statewide Integrated Traffic Records System (SWITRS) for the years 2005–2014. The data were cleaned and made available by the Safe Transportation Research and Education Center at the University of California, Berkeley via their Transportation Injury Mapping System (TIMS, 2017). Our analyses are based on geo-located pedestrian and bicyclist crashes that involved a motorized vehicle, for which a party most at fault was identified, and in which the nonmotorist age was provided. In preparing the data, we also follow Shen and Neyens (2017) and omit crashes involving exceptionally large vehicles such as buses and large trucks.

The SWITRS data include the following key characteristics of each crash:

- Injury severity (complaint of pain, visible injury, severe injury, fatality)
- Party at fault
- Age and gender of victim and driver
- Time of day
- Weather conditions
- Road conditions
- Lighting
- Location of collision (latitude and longitude)
- Intersection status
- Violation codes (i.e. "unsafe speed", "pedestrian violation")
- Sobriety of victim and driver
- Vehicle types involved

To complement the SWITRS data, additional data regarding the built environment and area demographics were obtained from the U.S. Census and SF OpenData, and spatially joined to the collision data using GIS. Added variables included bicycle lanes and other bicycle infrastructure, speed limits on all streets, and commuting characteristics by census tract.

The dependent variable in this study is injury severity, classified into four categories by police at the time of the crash: "Complaint of Pain" (COP), "Other Visible Injury", "Severe", and "Fatal". The police officer at the scene of the collision determined the severity of each injury based on the California Highway Patrol's *Collision Investigation Manual* (2003). The category "Fatal" is self-explanatory. The "Severe" category indicates injuries that require immediate medical attention, including broken bones, severe burns, and unconsciousness. Injuries classified as "Other Visible" include minor lacerations and bruises. Finally, "Complaint of Pain" can indicate anything from brief unconsciousness or limping and complaining of pain to "Persons who say they want to be listed as injured but do not appear to be so" (p 2–11).

Over the 10-year period from 2005 to 2014, the total number of pedestrian-vehicle collisions in San Francisco was approximately double that of bicycle-vehicle collisions, and there was a significantly higher percentage of serious injuries for pedestrians than for bicyclists (Fig. 1). Overall, 11% of pedestrian injuries were fatal or severe, compared to 6% of bicyclist injuries. Injury severity differed depending on the party at fault in the crash; when the pedestrian or bicyclist is at fault, the percentage of serious injuries is higher.

3. Theoretical framework and hypotheses

The literature that aims to illuminate why some road crashes are more severe than others is sizable, with multiple academic journals devoted to traffic safety and accident analysis. Though there are exceptions (e.g. the seminal Haddon Matrix, Haddon, 1972), it is surprisingly rare in this literature to see a conceptual map that graphically illustrates the relationships of interest. Fig. 2 is an intuitive concept map of the core determinants of crash injury severity for pedestrian and bicyclist victims, informed by the existing literature. The categories of factors include those that influence the crash forces (travel speed of all involved, vehicle size and type, crash angle, reaction time of all involved, and helmet use) and the health-related vulnerability of the victim (e.g., Elvik, 2011). Factors inside of dashed-line boxes are those that we do not have direct measurements of, and factors inside of solid-line boxes are those that we do have information about for each crash. As Fig. 2 makes clear, good measurements are not available for most of the relevant factors. Thus, analyses of the determinants of crash severity must rely on measurements of factors that we believe affect those in the dashed-line boxes.

Vehicle speed and the reaction time of all parties are critical determinants of crash severity (DiGioia et al., 2017; Elvik, 2004; Wang et al., 2013). Both whether a crash occurs and its severity are determined by the extent to which affected road users can take action (e.g., brake, swerve, and/or run) to avoid or reduce the severity of the crash. None of these factors are directly measured in the police reports, but related characteristics of the crash are measured, and it is these factors that dominate models of crash severity (including ours). These include factors such as weather and daylight affecting both initial speed (Elvik, 2004, citing Bjørnskau and Fosser, 1996) and reaction time; time of day, speed limit, and level of pedestrian and cyclist activity affecting initial travel speed (especially for vehicles due to traffic congestion); and the sobriety and wakefulness of all parties affecting reaction time.