



# Global bike share: What the data tells us about road safety



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## ABSTRACT

**Introduction:** Bike share has emerged as a rapidly growing mode of transport in over 800 cities globally, up from just a handful in the 1990s. Some analysts had forecast a rise in the number of bicycle crashes after the introduction of bike share, but empirical research on bike share safety is rare. The goal of this study is to examine the impact of bike share programs on cycling safety. **Methods:** The paper has two substudies. Study 1 was a secondary analysis of longitudinal hospital injury data from the Graves et al. (2014) study. It compared cycling safety in cities that introduced bike share programs with cities that did not. Study 2 combined ridership data with crash data of selected North American and European cities to compare bike share users to other cyclists. **Results:** Study 1 indicated that the introduction of a bike share system was associated with a reduction in cycling injury risk. Study 2 found that bike share users were less likely than other cyclists to sustain fatal or severe injuries. **Conclusions:** On a per kilometer basis, bike share is associated with decreased risk of both fatal and non-fatal bicycle crashes when compared to private bike riding. **Practical Applications:** The results of this study suggest that concerns of decreased levels of cycling safety are unjustified and should not prevent decision makers from introducing public bike share schemes, especially if combined with other safety measures like traffic calming.

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## 1. Introduction

Over a decade ago, Jacobsen (2003) published his landmark paper about 'Safety in Numbers' (SIN), showing that cyclists are less likely to be injured where volumes of cyclists are higher. This spurred a huge amount of research about SIN (Elvik & Bjørnskau, 2015; Elvik, 2009; Schepers et al., 2015). This paper aims to add to this branch of research by comparing crash risks of 'private bicycle riders' to those of bike share users that is interesting in relation SIN as volumes of cycling are (or become) typically higher where bike share programs are introduced.

Bike share safety has recently attracted a lot of attention (Bernstein, 2014). Prior to the introduction of North America's largest bike share program in New York City, a bicycle researcher was quoted in the *New York Times* predicting 'at least a doubling and possibly even a tripling in injuries and fatalities among cyclists and pedestrians during the first year' (Flegenheimer, 2013). This serves to highlight the safety concerns associated with bike share have been prominent at times, particularly around the launch of new programs. However, scientific research on the safety of bike share users is scarce (Fishman, 2015). The bike share literature, while all relatively recent, tackles a wide range of issues, from technological advancements (Ji, Cherry, Han, & Jordan, 2013), approaches to tracking bicycle movements and

rebalancing (Luong, Parikh, & Ukkusuri, 2014), research on bike share barriers and facilitators (Fishman, Washington, & Haworth, 2012), and quantification of impacts (Fishman, Washington, & Haworth, 2014; Fishman, Washington, & Harworth, 2015; Fuller et al., 2013; Zhang & Huang, 2012). Even though bike share has rapidly emerged as a new transport option in over 800 cities, from less than a dozen little more than a decade ago (Fishman et al., 2014), research on crash risk of bike share users is scarce.

Safety issues that have been addressed in research are operational cycling speed and helmet use. A higher cycling speed may be related to more severe crashes (Hu, Lv, Zhu, & Fang, 2014; Schepers, Fishman, Den Hertog, Wolt, & Schwab, 2014). A study among bike share users in Lyon showed that average operational speed—in real conditions and for average users—was 13.5 km/h, with the lowest speeds recorded on weekends (10 km/h) and fastest average speeds (15 km/h) on weekday mornings (Jensen, Rouquier, Ovtracht, & Robardet, 2010). Studies on private bike operational speeds in other countries tend to vary between 15 and 25 km/h meaning that operational speeds for bike share users are low (Allen, Roupail, Hummer, & Milazzo, 1998; Lin, He, Tan, & He, 2008). Bicycle helmets have been found to protect against head injuries (Bonander, Nilsson, & Andersson, 2014; Elvik, 2011). Helmets and bike share has been a contentious issue, with cities having to weigh the benefits of helmets in the event of a collision (Haworth, Schramm, King, & Steinhardt, 2010), with the difficulties of incorporating helmets within a bike share program (Fishman et al., 2012), such as losses from theft and hygiene issues. Observational studies conducted in Boston,

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Washington, DC, and London found that private bike riders were four times more likely to wear a helmet (Fischer et al., 2012; Goodman, Green, & Woodcock, 2013). In line with these results, Graves et al. (2014) found the proportion of head injuries among bicycle-related injuries to increase in North American cities after introduction of a bike share program.

To summarize, bike share users tend to ride at lower speeds and are reluctant to wear helmets. As the former is likely to improve cycling safety while the latter compromises cycling safety, behavioral research is not suitable to formulate hypotheses about safety. To our best knowledge, the only study including crash risk is by Woodcock, Tainio, Cheshire, O'Brien, and Goodman (2014) on the health impact of London's bike share program, which included road safety risk. The observed injury risks while using the cycle hire scheme were found to be lower than those estimated for cycling in general. The difference was significant for slight injuries and almost significant for serious injuries (Woodcock et al., 2014). Drawing firm conclusions has to be done with caution because, according to Woodcock et al. (2014), the analyses for serious injuries and fatalities were underpowered. As research on crash risk of bike share schemes is scarce, this study sets out to examine the impact of bike share programs on cyclist's crash risk. Based on the Woodcock et al. (2014) study, we hypothesize that bike share programs are associated with lower injury risks.

## 2. Materials and methods

Gathering high-quality bicycle crash injury data is a challenge, particularly because of underreporting of non-fatal bicycle crashes in the often used police crash databases. While police statistics are sufficiently complete for cyclist fatalities, hospital data are needed for victims treated at emergency departments or admitted to hospital (Langley, Dow, Stephenson, & Kypri, 2003; Schepers et al., 2015). This study examines injury risk associated with bike share programs using two substudies to make maximum use of the qualities of different data sources.

Study 1 is a secondary analysis of longitudinal hospital injury data from the Graves et al. (2014) study from 10 North American cities, divided into two categories: 5 bike share cities and 5 non-bike share cities. The analysis presented in the current study was not reported by Graves et al. (2014) because they focused on head injuries. Study 2 examines injury risk for bike share programs based on data provided by bike share operators who were contacted for this study. Although more cities were contacted, we present data only for the two large bike share programs of Paris and London, because these could be matched to general police reported bicycle injury data including cyclist fatalities, which is important given the low level of underreporting of fatalities. Both systems are open all year long.

### 2.1. Study 1: Longitudinal hospital data from bike share and non-bike share cities

Graves et al. (2014) assessed trauma center data for bicycle-related injuries. They compared cities that recently introduced bike share programs with cities that did not with 24 months before and 12 months after intervention data. Comparison cities were selected in similar geographic regions. The study did not distinguish between private bicycle riders and bike share users. This means that the outcomes relate to cycling safety in general with and without the introduction of bike share systems. In other words, the data are aggregated according to four conditions (before/after crossed with control/bike share).

Importantly, the Graves et al. (2014) study lacked exposure data. The study only provides injury counts under the aforementioned four conditions and an analysis of these data therefore relies on the assumption of exposure remaining constant before and after the introduction of bike share. However, as more cycling is the purpose of introducing bike share, we can safely assume that the volume of cycling increased in bike

share cities after the introduction of the programs (see, e.g., Fishman, Washington, & Haworth, 2013; Woodcock et al., 2014). This implies that if everything else remains equal, the increase of bicycle use in bike share cities after the introduction of a bike share program can be expected to increase the number of injuries among cyclists. As we don't know by how much, we only compare the number of injuries among cyclists before and after the introduction of the bike share programs. This means that our analysis leads to an overestimation of risk in terms of injuries per bicycle kilometer in bike share cities after the introduction of the bike share program. Due to this fact, we should bear in mind the risk of a Type II error, namely, not rejecting the null hypothesis that cities with and without bike share programs are equally safe, while bike share cities are actually safer. Practically, this means that we can only draw conclusions if the absolute number of injuries in bike share cities significantly decreases after the introduction of bike share because that would suggest that the risk decrease (in terms of injuries per bicycle kilometer) is greater than the increase of bicycle use (with injuries being the product of risk and kilometers traveled by bicycle). On the contrary, if the absolute number of injuries remains constant or increases, we are unable to distinguish between decreased risk and increased bicycle use. For instance, a 20% increase of injuries could result from a 20% lower risk and 50% more bicycle kilometers ( $0.8 \times 1.5 = 1.2$ ), but also from an unchanged risk and 20% more bicycle kilometers ( $1 \times 1.2 = 1.2$ ).

### 2.2. Study 2: Injury data from bike share users and private bicycle riders

This study examines injury risk for bike share programs in Paris and London. The study used fatal and serious injuries reported to the bike share operator. It is standard practice for bike share users to be required to report injuries to the bike share operator and, although it is possible (indeed likely) that some incidents fail to be reported, this measure has been used because it is a relatively easily captured data source and provides a comparable data source across different systems. In the bike share operator data used in this study, injury severity has been divided into fatal injuries and injuries needing hospital admission. A fatality is defined as a death occurring within 30 days of the crash (Department of Transport, 2013). The bike share operators were provided with a description of categories of severity (see Appendix 1), and asked to identify the number of incidents reported to them in each category, for 2013. Because of the high number of zero fatalities among bike share users in 2013, we searched for additional police reported fatalities among bike share users using reports by authorities in the same regions.

The respective bike share operator has provided ridership and system data. This includes the number of trips and trip duration, which allow for estimates for total distance traveled, by applying an assumed travel speed of 10.2 km/h. These data are captured automatically each time a bicycle is removed and returned to a bike share docking station (see Fishman, 2015). Speed estimates used in this study are derived from previous studies (Jensen et al., 2010). This speed is the travel speed which accounts for stops made between origin and destination, such as dwell times at intersections. Higher travel speeds for bike share users were reported by Rojas-Rueda, de Nazelle, Tainio, and Nieuwenhuijsen (2011), but we restrict to the lowest value by Jensen et al. (2010) to avoid underestimation of the risk of bike share users (a higher assumed speed contributes to a greater number of kilometers in the denominator of the risk ratio). We reflect on the sensitivity of the analyses for speed in Section 3.2.3.

To gain a measure of risk for private bicycle users, in terms of injury and fatality per unit of distance, travel survey data for the Paris region and Greater London were combined with police-recorded injury figures between 2009 and 2011. It should be noted that these sources do not allow the exclusion of the minority of bike share users. We reflect on this limitation in Section 5. Travel surveys generally collect one-day travel diaries of all members of households (e.g., among about 8,000

households per year for Greater London; Department of Transport, 2013) and 18,000 households for Île-de-France (DRIEA, 2013). Respondents are asked to report their journeys on a given day, their start and end location, start and end times, mode of travel, and so forth.

Using SPSS, a Chi-square test was undertaken to compare the observed injury numbers per system (private vs. bike share bicycles) with the numbers expected based on the amount of bicycle use per system. Additionally, we compared the risk in terms of injuries per bicycle kilometers between bike share users and private bicycle riders using a crude incidence rate ratio (IRR) based on Poisson regression with generalized linear models in SPSS. It has the following form:

$$IRR = (I_{BS}/D_{BS})/(I_{PB}/D_{PB}) = (I_{BS} * D_{PB})/(D_{BS} * I_{PB}), \quad (1)$$

in which  $I_{BS}$  and  $D_{BS}$  are the number of injuries and distance traveled by bike share users and  $I_{PB}$  and  $D_{PB}$  the number of injuries and distance traveled by private bicycle riders. The distance by bike share users is the product of their travel speed ( $V_{BS}$ ) and travel time ( $T_{BS}$ ). To describe the sensitivity of our analysis for the assumed travel speed, we can rewrite the formula for IRR as follows:

$$IRR = (I_{BS}/\{V_{BS} * T_{BS}\})/(I_{PB}/D_{PB}) = (I_{BS} * D_{PB})/(V_{BS} * T_{BS} * I_{PB}) = (1/V_{BS}) * (I_{BS} * D_{PB})/(T_{BS} * I_{PB}) \quad (2)$$

### 3. Results

#### 3.1. Study 1: Longitudinal hospital data from bike share and non-bike share cities

Fig. 1 shows the total number of injuries reported at trauma centers in bike share cities and control cities before and after the implementation of bike share programs. These figures are presented per year for a visual impression (the pre-period was 2 years; the post-period 1 year).

Table 1 presents the total injury figures for both city types before and after implementation. The Chi-square test is highly significant, showing that the total number of injuries per year in bike share cities decreased compared to a small increase in control cities. The drop is particularly striking because the amount of bicycle use is likely to have increased due to the introduction of the bike share program. If everything else would remain equal, an increase of bicycle use can be expected to yield a proportionally large increase of injuries. Apparently, the risk decrease is large enough to ‘overcompensate’ increased bicycle use and achieve a reduction of injuries. These outcomes show that cyclists’ injury risk decreased after the introduction of the bike share program.

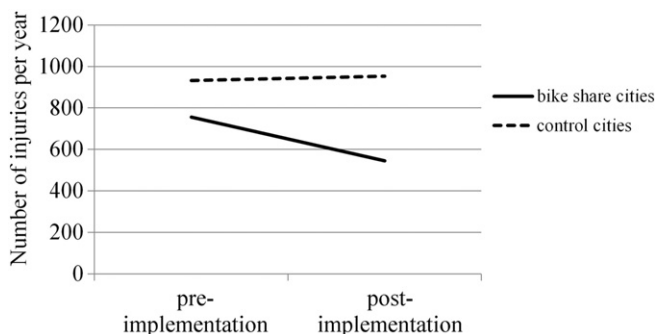


Fig. 1. Injuries per year in bike share cities and non-bike share cities (control) (Graves et al., 2014).

Table 1

Injuries in cities with bike share programs and control cities before (24 months) and after (12 months) introduction of bike share programs in the former ( $\chi^2(1, 4874) = 30.3$ ;  $p < 0.001$ )

City	Before (per year)	After	Total
Bike share cities	1,513 (757)	545	2,058
Control cities	1,863 (932)	953	2,816
Total	3,376 (1,688)	1,498	4,874

#### 3.2. Study 2: Injury data from bike share users and private bicycle riders

##### 3.2.1. System use and injury data

Table 2 details key metrics, in terms of size, use, and injuries provided by Paris and London bike share operators. The average number of trips per bike per day is illustrated and this offers an indication of how well a system is used, controlling for system size. Paris recorded the largest fleet, trips, and distance traveled. Paris also has the highest intensity of use. Other researchers have found that some 28% of all bicycle trips in Paris are covered by shared bikes (DRIEA, 2013). Table 2 also illustrates the number of injuries reported by users to bike share operators. Only London recorded a fatality in 2013.

##### 3.2.2. Comparing bike share injury risks to general bicycle injury risks

General bicyclist injury risks for Paris and London are shown in Table 3, using data collected for the jurisdiction known as Île-de-France (which encompasses Paris) as well as Greater London. In this analysis, travel survey data (Department of Transport, 2013; DRIEA, 2013) has been combined with police-recorded injury figures between 2009 and 2011 for Île-de-France (DRIEA, 2010, 2011) and Greater London (Transport for London, 2012). The table compares the 2013 injury risks of the Paris and London bike share systems to the injury risks in 2009–2011 in the jurisdictions of which these systems are part. The observed numbers of injuries are compared to the expected numbers based on kilometers traveled by private and bike share bicycles using a Chi-square test. For serious injuries, the injury risks are lowest for bike share.

Because of the high number of zero fatalities among bike share users in 2013 (see Table 2), we instead calculated an average fatality risk by adding Paris data collected between 2007 and 2012, during which time police recorded eight deaths among bike share users (Byrne, 2013). Usage during this time period is estimated at some 0.58 billion-bicycle kilometers. By combining these figures to those in Tables 2 and 3 for Paris and London, a bike share fatality rate of some 13 per billion bicycle kilometers (9 fatalities divided by 0.72 billion bicycle kilometers) has been estimated. This is significantly lower than the 25 fatalities per billion bicycle kilometers for private bicycle riding.

Table 3 also includes incidence rate ratios which describe to size of the risk difference. A ratio below 1 indicates that the risk is lower for bike share users. The incidence rate ratios are close to 0.5 for both serious and fatal injuries.

##### 3.2.3. Sensitivity of the analysis related to the assumed travel speed

As described in Section 2.2, we assumed the lowest travel speed of 10.2 km/h that we could find in the literature for bike share users (Jensen et al., 2010), while Rojas-Rueda et al. (2011) found speeds as high as 14 km/h. Formula 2 in Section 2.2 describes that the incidence rate ratio is proportional to the inverse to bike share travel speed ( $V_{BS}$  in Formula 2). By assuming a 14 km/h travel speed instead of 10.2 km/h, the incidence rate ratios in Table 3, decrease by a factor 0.73 ( $14^{-1}/10.2^{-1}$ ), from 0.41 and 0.50 for serious injuries and fatal injuries, respectively, to 0.37 and 0.30. This difference of almost 30% suggests that more reliable data about travel speed and distance are needed to draw firm conclusions about the absolute size of the risk difference between bike share and private bicycles.

**Table 2**

Paris and London bike share programs, size, usage, and injury data, 2013

City	Ave. no. bicycles in fleet	Total trips for 2013	Ave. no. trips per day per bike	Est. ave. trip duration (min)	Est. distance traveled per year (km)	Serious injuries	Fatalities
Paris	18,130	35,021,999	5.3	20	118,607,837	19	0
London	9,083	8,045,459	2.4	17.5	23,841,377	17	1

#### 4. Discussion

We conducted two studies to examine the risks associated with bike share and to test our hypothesis. Both Study 1 and 2 provide support for our hypothesis that bike share programs are associated with lower injury risks. Study 1 indicated that the introduction of a bike share system is associated with a reduction in cycling injury risk. Study 2 found that bike share users are less likely than other cyclists to sustain fatal or severe injuries. These outcomes are in line with the study by Woodcock et al. (2014), which is, to the best of our knowledge, the only published research that included the impact of bike share on road safety risks.

An explanation for bike share users' lower road safety risk is not immediately obvious. One explanation is SIN, that is, increased driver awareness and cautiousness towards cyclists (Jacobsen, 2003), as drivers encounter more cyclists after the introduction of bike share systems. The focus on the specific group of bike share users also introduces potential explanations related to the specific characteristics of bike share users. One explanation might be that their speeds are substantially lower than for other cyclists, which has been found to reduce injury risk (Schepers et al., 2014). Bike share speeds are generally in the same range as among cyclists in countries with high volumes of cycling such as The Netherlands (Jensen et al., 2010; Van Oijen, Lankhuijzen, & Van Boggelen, 2013). A slower speed increases the time available for cyclists to avoid crashes that may have occurred at higher velocities. It is also possible that motorists perceive bike share users to be less experienced and/or tourists and display greater level of caution, as revealed in qualitative research on perceptions of bike share (Fishman et al., 2012). The notion that drivers behave differently depending on the appearance of the cyclist has been established by Walker (2007), who found that drivers overtook closer to helmeted cyclists. Finally, compared to private bicycles, bike share users may frequently ride on roads in or nearby city centers where motor vehicles speeds are lower and injuries are less

severe (Kaplan, Vavatsoulas, & Prato, 2014; Schepers, Heinen, Methorst, & Wegman, 2013). More research is still needed to explain why cyclists are safer in jurisdictions with higher volumes of cycling (Bhatia & Wier, 2011; Jacobsen, 2003). Our finding that certain groups of cyclists within one jurisdiction run a decreased risk provides additional hypotheses and research opportunities.

The study had a number of limitations. The comparison of injury numbers in Study 1 lacks exposure data. The absolute number of injuries decreased while an increase could be expected because bike share tends to increase bicycle use (see, e.g., Fishman et al., 2013; Woodcock et al., 2014). We would actually like to know by how much risk in terms of injuries per bicycle kilometers decreased, but that is only possible with information about both injuries and bicycle kilometers. We recommend a study similar to the one by Graves et al. (2014), which includes ridership data to estimate the absolute size of the risk decrease. Such a study could be enhanced even further if injuries can be split among bikes share users and private bicycle riders.

This study also has a number of limitations. Firstly, the comparison of serious injuries in Study 2 is hampered by the fact that our data for bike share were reported to operators while data for other cyclists were based on police statistics. This raises the question of whether a high underreporting rate for the former data source contributed to the low risks we found for bike share. While contacting cities with bike share programs, Montreal was the only city that could provide detailed information regarding crash types. About half of the crashes were crashes with no motor vehicle involved. This is less than the share of non-motor vehicle crashes reported in medical registrations which ranges between 60% and 95% (Schepers et al., 2015). On the contrary, the police rarely report these crashes (Haworth et al., 2010; Langley et al., 2003). The substantial numbers of non-motor vehicle crashes reported to bike share operators is indicative of a higher reporting rate of injuries among cyclists than is to be expected for police statistics. Including 'bike share' as an option on police and hospital incident forms in cities with bike share would enhance data for both groups of cyclists. Secondly, we were not able to exclude the minority of bike share injuries from the majority of police-reported private bicycle injuries. What the authors referred to as a 'private bicycle risk' is actually the general bicycle risk that now contains the relatively low-risk bike share users. Thirdly, reliable data about ridership among bike share users (the denominator of risk) is equally important as reliable injury data (the numerator of risk). To achieve a conservative estimate of the risk of bike share users, we assumed the lowest travel speed of 10.2 km/h reported by Jensen et al. (2010). Assuming the 14 km/h travel speed among bike share users reported by Rojas-Rueda et al. (2011), would have yielded an almost 30% lower rate ratio and would suggest the risk among bike share users is even lower than we described in this paper. Because of the aforementioned three limitations, it could be that the actual injury risks of bike share users are more reduced compared to private bike riders than our outcomes suggest, which is why we cannot draw firm conclusions on the absolute risk difference.

#### 5. Conclusions and recommendations

The results of our two substudies lead us to conclude that, on a per kilometer basis, bike share is associated with decreased risk of both fatal and non-fatal bicycle injuries when compared to private bike riding. This contradicts worries prior to the introduction of some of the currently existing bike share schemes (e.g., Fleggenheimer, 2013).

**Table 3**

Injuries and fatalities, bicycle use and injury rates between for private and bike share users in Ile-de-France and Greater London

Injury numbers	Serious injuries	Fatalities
Private bicycle	2,015	79
Bike share	36	9
<i>Bicycle use (billion km)</i>		
Private bicycle	3.19	3.19
Bike share	0.14	0.72
<i>Expected based on bicycle use<sup>1</sup></i>		
Private bicycle	1,964.8	71.8
Bike share	86.2	16.2
<i>Observed versus expected based on bicycle use</i>		
Chi-square	31.5	3.9
P	<0.001	0.048
<i>Injury risks per billion km</i>		
Private bicycle	631	25
Bike share	253	13
Crude incidence rate ratio (95% CI) <sup>2</sup>	0.41 (0.29 to 0.57)	0.50 (0.25 to 1.00)

<sup>1</sup> The product of the total number of injuries and the share of bicycle kilometers per condition, e.g., for private bicycle:  $(2015 + 36) * (3.19/3.33) = 1964.8$ .

<sup>2</sup> Incidence rate ratio: injury risk bike share/injury risk private bicycle; CI assuming a Poisson distribution.



Notwithstanding the importance of improving conditions and safety for cyclists by, for instance, traffic calming (Jacobsen & Rutter, 2012), these results imply that concerns about decreased levels of cycling safety are unjustified and should not prevent decision makers from introducing public bike share schemes.

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## Appendix 1. Injury severity reporting classification

This Appendix describes the three categories of severity (slight, serious and fatal) provided to the bike share operators for Study 2. These definitions are consistent with Department of Transport (2013) guidelines.

### 1.1. Slight injury

An injury of minor character such as a sprain (including neck whip-lash injury), bruise or cut which are not judged to be severe, or slight shock requiring roadside attention. This definition included injuries not requiring medical treatment.

### 1.2. Serious injury

An injury for which a person is detained in hospital as an "in-patient", or any of the following injuries whether or not they are detained in hospital: fractures, concussion, internal injuries, crushings, burns (excluding friction burns), severe cuts and lacerations, severe general shock requiring medical treatment and injuries causing death 30 or more days after the accident.

### 1.3. Fatal

Human casualties who sustained injuries which caused death less than 30 days after the accident. Confirmed suicides are excluded.

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