Motor Vehicle Crashes Involving a Bicycle Before and After Introduction of a Bike Share Program in Philadelphia, Pennsylvania, 2010–2018

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Objectives. To quantify the impact of a citywide bicycle share program on rates of motor vehicle collisions involving a bicycle.

Methods. We conducted an interrupted time series analysis, using crash records from the Pennsylvania Department of Transportation for Philadelphia County from 2010 through 2018. We also calculated summary statistics to illustrate annual and monthly trends in rates of motor vehicle crashes involving a bicycle.

Results. The baseline rate of bike events was 106% greater (95% confidence interval [CI] = 1.25, 3.38) at the time bicycle share was implemented compared with January 2010. Before bicycle share implementation, the rate of bicycle events decreased 1% (95% CI = 0.95, 1.03) annually. After the bicycle share program started, the rate of bicycle events decreased 13% (95% CI = 0.82, 0.94) annually.

Conclusions. In the long term, programs that increase the number of bicycles on the road, such as bike share, may reduce rates of motor vehicle crashes involving a bicycle. (*Am J Public Health.* 2020;110:863–867. doi:10.2105/AJPH.2020.305613)

Micromobility programs are a growing presence in US cities. Bicycle share programs, a form of micromobility, provide an alternative to urban automobile-based transportation. Bicycle-sharing systems may be public, private, or joint ventures using docked and dockless systems with standard and electric bicycles. Some are limited to specific geographic areas of a city, whereas others span entire metropolitan areas. Today, there are nearly 900 bicycle-sharing companies[1] worldwide. The National Association of City Transportation Officials estimates that there were 36.5 million station-based and 6 million dockless bicycle share trips in the United States in 2018, up from 35 million just the year before.[2] This can be attributed to the introduction of new programs and the expansion of existing programs. The National Association of City Transportation Officials estimated that 57 000 bicycles were available via station-based bicycle share in 2018 alone.

Micromobility programs are appealing; they are a sustainable, inexpensive, and healthy[3] transportation alternative to personal motor vehicle use (e.g., automobile, motorcycle), which are responsible for congestion, noise, and air pollution.[4,5] Indeed, 1 report suggested that replacing a single passenger vehicle that averages 28 miles per gallon per passenger with an e-scooter could reduce carbon dioxide emissions by 98%.[6] US cities have developed a transportation infrastructure almost exclusively for motor vehicles; the lack of infrastructure for micromobility programs raises concerns about the safety of individuals who use these programs.

On April 23, 2015, the city of Philadelphia, Pennsylvania, introduced the Indego bicycle share program. Bicycles can be borrowed by anyone aged 14 years or older on a one-time basis, for a single hour or day, or individuals can subscribe to monthly or annual membership programs with the use of a credit card. Since its introduction, Indego has grown in terms of use, as indicated by the number of annual trips taken and stations and bicycles available. For example, in its first quarter of operation (April–June 2015), Indego introduced approximately 600 bicycles and had nearly 120 000 trips. In the fourth quarter of 2018, Indego managed more than 1300 bicycles and in the second quarter of 2019, it had more than 205 000 trips. In 2019, Indego expanded to include more than 400 pedal-assisted electric bicycles.

From a healthy policy perspective, the implementation of a bicycle share program, such as Indego, can be viewed as an intervention with potential impacts on health and health behavior. Overall, people who ride a bicycle frequently are more physically active than are their peers and enjoy cardiovascular benefits and a lower risk of early death.[7–9] Although there are health benefits, bicycle users experience a higher risk of being a victim of a road traffic injury or death per trip compared with other road users, except motorcyclists.[10]

The key risk factors affecting bicyclist crash risk[11] include separation from motor vehicle traffic and other road design factors,[12–19] the speed of motor vehicle traffic,[20] nighttime and other visibility conditions,[21,22] demographic characteristics,[23] and both motorist

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This article was accepted January 30, 2020.
doi: 10.2105/AJPH.2020.305613

and cyclist behaviors, such as alcohol or smartphone use.[22,24–27] Despite their widespread adoption over the past 2 decades, there is little empirical evidence regarding the safety of bicycle share programs.[7,28,29]

Because these programs provide immediate access to bicycles for entire cities, especially when implemented in more population-dense areas, their impacts can be quantitatively evaluated using policy-oriented statistical methods. To this end, we conducted an interrupted time series analysis to evaluate trends in motor vehicle crashes involving a bicycle before and after implementation of the Indego bicycle share program in Philadelphia from 2010 to 2018.

METHODS

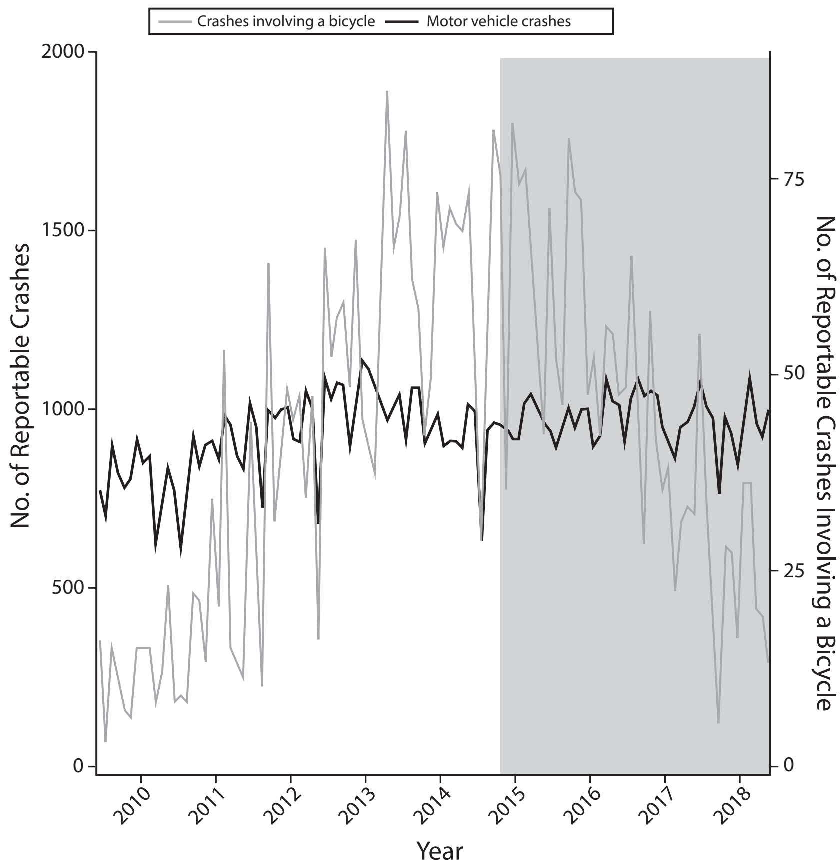
To evaluate the impact of the Indego bicycle share on motor vehicle crashes involving a bicycle, we used publicly available road traffic crash data from the Pennsylvania Department of Transportation Public Crash Database.[30] The database contains a record of all reportable crashes, defined by Pennsylvania state law (Title 75, Pennsylvania Consolidated Statutes, Section 3746(a)) as involving at least 1 motor vehicle and having occurred on a public road. Further, the event must have led to at least 1 injury (or death) or damaged a vehicle to such an extent that it could no longer be driven and must have involved a police officer. All records that involve a bicycle also noted, at minimum, a minor injury. We considered all records regardless of age or any other individual level factors.

We combined all records for Philadelphia County from January 1, 2010, through December 31, 2018, for our analysis. We selected this period because of data availability and to adequately capture the periods before and after the implementation of the bicycle share program in Philadelphia. Each record contains an indicator of whether a bicycle was involved in the crash. Thus, we were able to calculate the proportion of total reportable crashes that involved a bicycle. Records for crashes that involved a major injury or death of a bicyclist exist. Major injuries are defined as an injury that incapacitated an individual and required transportation from the crash scene. Because the total number of bicyclist major injuries or deaths was small, we did not specifically evaluate their trends before and after bicycle share implementation.

We calculated the proportion of reportable motor vehicle crashes involving a bicycle (hereafter "bicycle events"), per month, from January 2010 through December 2018. We converted these proportions to rates of bicycle events per 1000 reportable motor vehicle crashes. We described both the number of bicycle events and reportable crashes as well as the rate of bicycle events using graphical summaries to illustrate trends over time, including seasonal and yearly trends.

We treated the introduction of Indego bicycle share on April 23, 2015, as a citywide policy intervention and the time at which the time series was interrupted. We parameterized bicycle share as a binary variable, which we coded zero for all observations before the introduction of Indego and 1 for all observations after the introduction. Because we aggregated the data by month, we treated the start of Indego as having occurred on May 1, 2015. Because the number of available bicycles and stations increased steadily over time since the introduction of the bicycle share, we applied a level and slope change as our primary model structure.[31] This model integrates an interaction term between time and a binary indicator of bicycle share to allow the possibility of a change in trends of bicycle events after the implementation of bicycle share.

We assumed a quasi-Poisson distribution for the outcome and included the log of the total number of crashes as the offset term. In addition, adjusted models accounted for seasonal trends using a natural cubic spline with 11 knots to account for monthly changes in bicycle event rates; this is the only covariate included in adjusted models. We repeated our analysis, treating the intervention as starting in July 2015, a month for which bicycle use



Note. The grayed area notes data for the period after implementation of bicycle share.

FIGURE 1—Total Number of Reportable Motor Vehicle Crashes and Reportable Crashes Involving a Bicycle, per Month: Philadelphia, PA; January 2010–December 2018

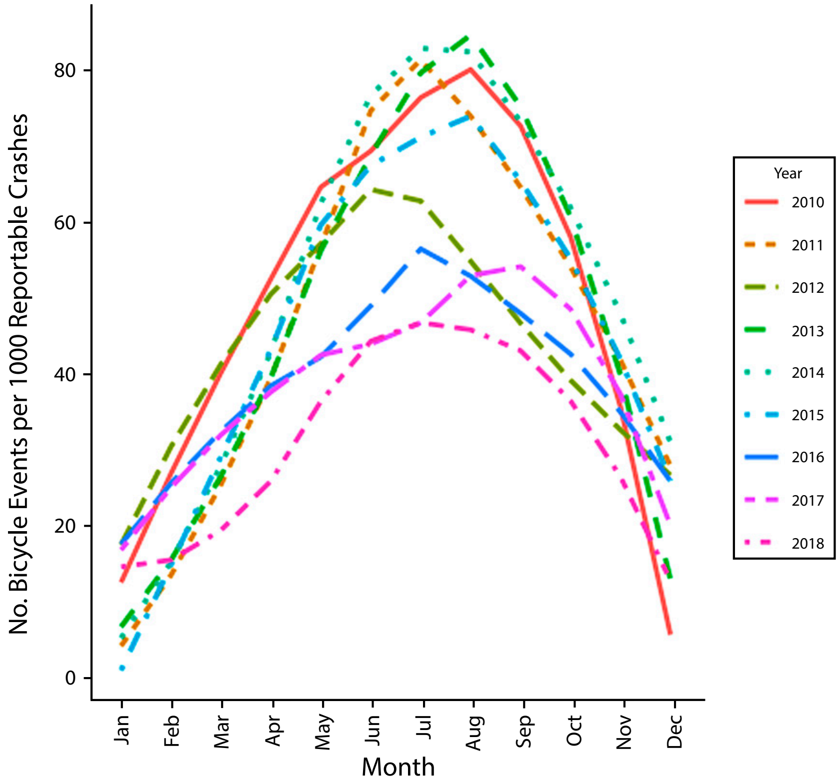
tends to increase, rather than May 2015. This allowed a lag effect in uptake of bicycle share. We also explored nonlinear time trends in sensitivity analyses.

We conducted all analyses using R version 3.6.0 (R Foundation for Statistical Computing, Vienna, Austria). All of the data used to generate results for our study are publicly available. Both data and statistical code necessary to reproduce the results of this work can be obtained from G. B.H.'s personal Web page (http://ghassanbhamra-phd.org) and are provided as an Appendix (available as a supplement to the online version of this article at http://www.ajph.org).

RESULTS

There were 101 074 reportable motor vehicle crashes between 2010 and 2018. Of these, 4479 involved a bicycle. Figure 1 shows the total numbers of reportable motor vehicle crashes and reportable motor vehicle crashes involving a bicycle, per month, from January 2010 through December 2018. The total number of reportable motor vehicle crashes was relatively stable over this period. By contrast, there was a notable increase and subsequent decrease in the total number of reportable motor vehicle crashes involving bicycles over this same period. Figure 2 uses a smoothing function to aid in visualizing trends; a version of Figure 2 without a smoothing function is provided in Figure A (available as a supplement to the online version of this article at http://www.ajph.org). Figure 2 displays the rates of bicycle events for each month and year. Bicycle event rates demonstrate a clear seasonal pattern, with peaks in the summer and sharp declines in the winter months. There was a decline in the rate of bicycle events in the years following the implementation of bicycle share compared with most previous years.

Results of unadjusted models were not materially different from results of adjusted models and, thus, are not presented. Between May 1, 2015, and December 31, 2018, the period following the implementation of the bicycle share program, the rate of bicycle events decreased by 13% (95% CI = 0.82, 0.94), on average, each year. By contrast, between January 1, 2010, and April 30, 2015, the period before the introduction of bicycle share, the rate of bicycle events decreased, on average, by 1% (95% CI = 0.95, 1.03) each year; notably, the CI indicates that the data are also consistent with no change and a slight increase in bicycle events before implementation of bicycle share.



Note. Lines are smoothed to aid visualization.

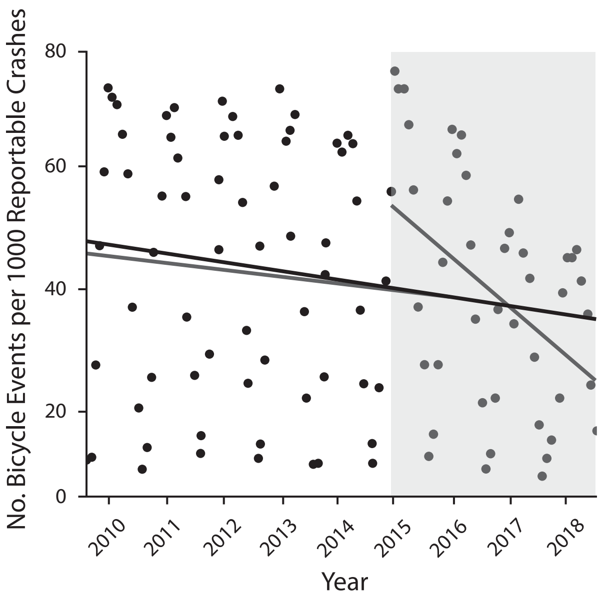
FIGURE 2—Rate of Motor Vehicle Crashes Involving a Bicycle, per Month: Philadelphia, PA; January 2010–December 2018

The rate of bicycle crashes in January 2010, the baseline rate for the preintervention period, was 15 per 1000 reportable motor vehicle crashes. The baseline rate of bicycle events in the month after bicycle share (May 2015) was 31 per 1000 reportable motor vehicle crashes, or 106% (95% CI = 1.25, 3.38) greater than the pre–bicycle share baseline rate. Figure 3 illustrates the trends over time before and after bicycle share; the points on this figure are predicted bicycle event rates based on our adjusted model. The slope line (dark gray) fitted to bicycle events over time was negative both before and after bicycle share implementation. However, compared with before, the slope line is steeper after the introduction of bicycle share. A slope line was also fitted for the expected linear trend in the absence of bicycle share (black). The slope was negative, and largely followed the preintervention slope line (dark gray).

We explored departures from linearity in sensitivity analyses but found that the trends were consistent in that they were generally downward; this can be viewed in Figure B (available as a supplement to the online version of this article at http://www.ajph.org). Finally, results of analyses that applied a lag for the start of bicycle share did not materially change our results and, thus, are not presented.

DISCUSSION

To our knowledge, this is the first analysis of its kind to evaluate rates of motor vehicle crashes involving bicycles (and, thus, injuries to bicyclists from motor vehicles) treating bicycle share as a policy intervention. Results from our analysis suggest that the rate of bicycle events decreased more rapidly after the initiation of bicycle share. Results from this analysis have important implications for



Note. Lines are fitted to the predicted proportions ignoring the implementation of a bicycle share program (black) and to the data before and after implementation (dark gray).

FIGURE 3—Predicted Rate of Monthly Motor Vehicle Crashes Involving a Bicycle: Philadelphia, PA; January 2010–December 2018

bicycle share and other micromobility programs.

With the rapid growth of micromobility programs globally, it is critical that we understand their positive—and negative—impacts. It is well established that the use of bicycles generally supports physical activity and, thus, physical and mental health over use of personal motor vehicle transportation.[3] The potential adverse impacts of share programs are less well known. One previous study suggested an increase in the proportion of head-specific injuries among all bicycle injuries recorded at trauma centers after initiation of bicycle share in 5 cities compared with control cities.[28] However, multiple responses to this analysis dispute the interpretation of its findings[32] and noted that, in fact, the total number of bicycle injuries decreased in the bicycle share cities after implementation.[33] We found that the rate of bicycle events decreased more rapidly following implementation of bicycle share. This is consistent with other studies and theories on behavioral changes resulting from an increased presence of micromobility in cities.

A study of Citi Bicycle share by the New York City Department of Transportation in 2017 reported a 17% drop in the number of cyclists killed or severely injured in the bicycle share zone 1 year after the program was initiated.[34] In Boston, Massachusetts, a large-scale expansion of bicycle infrastructure was credited with increasing bicycle commuting and decreasing injury rates between 2007 and 2014.[35] In Dublin, Ireland, a bicycle share program was credited with increasing the number of daily bicycle commuters without increasing the number of cyclist injuries.[36] Most notable in our study and that in New York City is that the total number of cyclist injuries decreased despite an increase in the number of bicycle commuters. A report by the Center City District in Philadelphia noted a 79% increase in bicycle commuter traffic on a subset of major roads from 2010 to 2016 and a 22% increase from 2014 to 2016; 6% of bicycle traffic in 2016 was attributable to Indego bicycle share.[37]

This may seem counterintuitive, as an increase in the number of bicycle users over time might be expected to result in a proportional increase in the number of bicycle-related crashes. There are 2 theories forwarded to explain why an increasing numbers of bicycle users could lead to a decrease in the proportion of motor vehicle crashes involving a bicycle: changes in infrastructure to accommodate more bicycle commuters[38] and the safety in numbers theory.[30] To our knowledge, there were no large-scale infrastructure changes, such as adding numerous protected bicycle lanes across Philadelphia, that could potentially explain the change in the trend during the period under examination.

The observed effect may reflect the safety in numbers theory. This posits that as more individuals choose alternative modes of transit, such as bicycling or walking, motor vehicle commuters change their driving behavior; the result is a decreased injury risk. A summary of injury risk among pedestrians and bicyclists from 5 studies in multiple cities and countries supports this theory. Notably, this study showed that as the number of pedestrians and bicyclists increased, injury risk decreased, whereas the absolute number of injuries increased.[30] We note that our study found not only a decreased injury rate but also a decrease in the absolute number of bicyclist injuries (i.e., motor vehicle crashes involving a bicycle). If the safety in numbers theory is correct, cities seeing an increase in bicycle commuters should encourage uptake of micromobility to further normalize the practice and, thus, reduce crash (and injury) risk.

Strengths of this work include the use of a robust and comprehensive record of road traffic crashes involving a bicycle available from the Pennsylvania Department of Transportation and a well-defined intervention. We used an interrupted time series design, which is a strong analytic approach that, by comparing the same area (Philadelphia) to itself over time, controls for a number of time invariant factors that we would otherwise be concerned about as confounders.

Despite these strengths, we must acknowledge several limitations. First, because the geographic range for the Indego bicycle share is unrestricted (i.e., bicycles can travel anywhere after they are checked out from a station), we could not reasonably assume that any specific area in the city was unexposed to bicycle share. Thus, a more rigorous comparative interrupted time series analysis was not possible, because an area in Philadelphia would have had to have been unexposed to bicycle share. Second, our data are restricted to reportable crashes. As described in the Methods, this necessitates involvement of a motor vehicle and police officer. Thus, bicycle crashes not involving a motor vehicle or those that did not result in a police report are missing.

We, therefore, emphasize the importance of restricting any interpretation of our findings to the impact of bicycle share on reportable motor vehicle crashes involving a bicycle.

We controlled for seasonal trends in our analysis, but it is possible that there was residual confounding by other time-varying factors for which we were unable to control in this analysis. Another limitation is that we did not examine the impact of bicycle share on the severity of injuries attributable to a change in the definition of severity of injury by Pennsylvania on January 1, 2016, which was during the evaluation period.[30] Finally, we were unable to examine the impact on bicyclist major injuries and deaths because of too few events.

Our analysis showed an accelerated decrease in motor vehicle crashes involving a bicycle after the introduction of a citywide bicycle share program in Philadelphia. There is a need for further work on this topic, exploring whether the temporal patterns we observed in Philadelphia are consistent in other cities, whether there are spatial patterns in bicycle share–related crashes, the impact of the bicycle share on other types of bicycle-related injury, the impact of other types of micromobility programs on injuries, and what modifiable factors prevent or precipitate bicycle share–related injury events. Micromobility programs are sustainable and cost-effective programs that promote healthy behaviors. Reassuringly, our results suggest that, in the long run, bicycle share programs do not lead to increases in the rates of bicyclist injuries caused by crashes with motor vehicles and, in fact, may accelerate their decrease. AJPH

CONTRIBUTORS

G. B. Hamra conceptualized the work and led all phases of analyses and writing. L. H. Schinasi and D. A. Quistberg drafted text and interpreted findings.

CONFLICTS OF INTEREST

G. B. Hamra, L. H. Schinasi, and D. A. Quistberg are all users of the Indego bicycle share program, the intervention that was the focus of this work.

HUMAN PARTICIPANT PROTECTION

No protocol approval was necessary because no human participants were involved in this analysis.

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