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Advancing healthy cities through safer cycling: An examination of shared lane markings

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ABSTRACT

To advance healthy transportation via increased bicycling, cities combat one of the primary barriers to such cycling – traffic safety concerns – through the provision of various bicycle treatments. Shared lane markings (more commonly known as “sharrows”) are an increasingly common treatment utilized to improve bicyclist safety. While past research confirms that sharrows may effectively influence spacing and other operational measures, the impact on actual safety outcomes remains unsubstantiated due to a lack of dooring-related bicycle crash data. Fortunately, the city of Chicago instituted a program to collect dooring crash data in 2010. Thus, the purpose of this research is to longitudinally examine the association between sharrows and bicyclist injuries by combining traditional crash data with dooring-related crash data.

To perform this examination, we divide Census block groups in Chicago into three categories based on what bicycle treatment was installed between the years 2011 and 2014: (i) those block groups with no bicycle facilities installed; (ii) those with only sharrows installed; or (iii) those with only bicycle lanes (standard, buffered, and/or protected) installed. Negative binomial regressions and Kruskal–Wallis tests suggest that block groups with only sharrows installed experienced the largest increase in bicyclist injury rates, with exposure being accounted for through levels of bicycle commuter activity. This relationship held true for overall crashes as well as for dooring-related crashes. These findings raise concerns regarding the safety effectiveness of sharrows as used by the City of Chicago during the study period and should be a call for more research on the subject in a variety of different contexts using various exposure metrics.

1. Introduction

Bicycling has been shown to have an overall positive impact on the health of those who ride (de Hartog et al., 2010; Rojas-Rueda et al., 2011; Deenihan and Caulfield, 2014). However, one of the primary barriers to bicycling is traffic safety concerns (Fowler et al., 2017). By improving traffic safety outcomes for bicyclists, we can expect not only direct health benefits in terms of reduced injuries and fatalities, but indirect health benefits accrued through greater participation and increased

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physical activity. Research has also shown that cities with elevated levels of bicycling have better safety outcomes for all road users and lower air pollution, further amplifying the health benefits of bicycling (Marshall and Garrick, 2011; Johansson et al., 2017). In terms of advancing healthy cities, enabling more bicycling through improved safety is a worthy cause.

One common method of improving traffic safety for bicyclists is through the implementation of bicycle treatments and facilities. An extensive toolbox of such treatments exists, ranging from signage and wayfinding to dedicated and protected facilities exclusive to bicyclists. One of the most widely used treatments is the shared lane marking (Fig. 1).

Shared lane markings – more commonly known as sharrows – trace their origins to Denver, Colorado in the early 1990s (Alta Planning + Design, 2004; Pein et al., 1999). The markings were initially purposed to improve bicyclist safety by raising driver awareness of bicyclists and reducing wrong-way riding (City and County of Denver, 1993). They have since evolved to serve several different functions such as reducing sidewalk riding and avoiding collisions with the doors of parked cars (i.e. dooring crashes) (U.S. Department of Transportation, 2009; National Association of City Transportation Officials (NACTO), 2011). In 2009, sharrows were added to the Federal Highway Administration's Manual on Uniform Traffic Control Devices (MUTCD), solidifying their place as an accepted bicycle treatment (U.S. Department of Transportation, 2009). The markings have become a popular substitute for more expensive and expansive alternatives such as bicycle lanes and cycle tracks. Today, sharrows comprise the majority of nearly every major U.S. city's bicycle network and have become a staple in the toolboxes of transportation planners and engineers. However, little past research has adequately examined whether these markings help make bicyclists safer.

One of the primary reasons for this absence of safety research is the lack of data on dooring crashes. Since one of the stated justifications for sharrow installation is to help move bicyclists out of the door zone, a safety analysis without dooring crashes would be insufficient. Nearly all cities neglect dooring crashes because the crashes do not involve a moving motor vehicle, therefore failing to meet the standard of what constitutes a motor vehicle crash. One of the only exceptions is the City of Chicago. In 2010, the City of Chicago initiated a program to collect dooring crash data. The release of this dooring crash data marks the first time that the impact of sharrows on bicyclist safety can begin to be properly studied.

With their popularity rising in cities across the country, this paper aims to longitudinally examine safety outcomes – in terms of bicyclist injuries – of Chicago block groups that had sharrows installed against block groups that installed bicycle lanes (standard, buffered, and/or protected) as well as those that added no new bicycle facilities. More specifically, we investigate changes in bicyclist injury counts within these treatment typology groups by utilizing negative binomial regressions. We then analyze changes in injury rates between the different typologies through a Kruskal–Wallis test.

Fig. 1. Example of a sharrow.

Over the past two decades, interest in bicycling has continued to increase across the United States and the health benefits of such activity have become better understood. Coinciding with this increased interest in bicycling, sharrows have become a standard bicycle treatment. However, a void exists in the research as to how these treatments link to actual safety outcomes. This paper will utilize spatial and statistical analyses to examine the relationship between sharrows and bicyclist injuries.

2. Literature review

Although their overall goal is to improve bicyclist safety, the exact operational function of sharrows is multifaceted and seems to have evolved over time. Many early studies that examined sharrows identified the altering of bicycle and vehicle spacing as an objective, including the spacing of bicyclists to avoid dooring crashes (Alta Planning + Design, 2004; U.S. Department of Transportation, 2010; Pucher et al., 2010). Similarly, four of the MUTCD's five objectives for sharrows deal with lateral spacing, the first of which is to assist bicyclists with lateral positioning to help bicyclists avoid impacting the open door of a parked vehicle (U.S. Department of Transportation, 2009). While results are mixed, past studies suggest that the effects of sharrows on spacing tend to be theoretically positive (Hunter et al., 2011, 2012; Brady et al., 2010). In other words, the mean distance between bicycles and parked cars, between bicycles and the curb, and between bicycles and moving vehicles can increase up to 10.5 inches with the installation of sharrows, which gives bicyclists more space to operate, and in theory, safer operating conditions (Hunter et al., 2011, 2012; Brady et al., 2010; Sando, 2014). However, other studies suggest no significant changes in lateral spacing at certain sites (Pein et al., 1999).

Today, this objective of altering spacing is less often the primary aim when installing a sharrow. Guidelines such as the MUTCD and NACTO's Urban Bikeway Design Guide recommend using sharrows to accomplish a variety of other operational objectives, such as alerting road users of bicyclists' presence, encouraging safe passing behaviors, reducing wrong-way riding, indicating the proper riding path over hazards such as railroad tracks, functioning as wayfinding devices, and reducing sidewalk riding (U.S. Department of Transportation, 2009; NACTO, 2011).

The academic community has focused on the impact that sharrows have on these other operational measures as well (Pein et al., 1999; Furth et al., 2011; Hunter et al., 2011, 2012). Overall, past studies have reported inconsistent findings regarding the installation of sharrows in terms of weaving through vehicle queues, sidewalk riding, and wrong-way riding (Hunter et al., 2012; Alta Planning + Design, 2004; U.S. Department of Transportation, 2011; Brady et al., 2010). While sharrows have been used to accomplish a wide array of operational objectives with varying levels of success, the impact on the overall goal of improved bicyclist safety has been largely neglected (Brady et al., 2010), despite the fact that existing research implies a direct benefit to safety without examining crashes, injuries, or fatalities (Alta Planning + Design, 2004; Hunter et al., 2011, 2012; Brady et al., 2010).

The lone piece of research that we found examining the impact that sharrows have on safety outcomes suggests that sharrows may be less safe than other bicycle treatments or even less safe than having no bicycle treatments present at all (Harris et al., 2013). Although not reaching statistical significance, results of Harris et al. (2013) suggest that sharrows increase bicyclists' risk of injury at non-intersection locations while cycle tracks and bicycle lanes significantly decrease bicyclists' risk of injury compared to similar roadways that lacked bicycle infrastructure. This case-crossover study, which took place in Vancouver and Toronto, Canada, examined adult bicyclists who were injured and treated at a hospital. The researchers identified the injury location (the case site), selected two other locations along each bicyclist's route (control sites), recorded roadway characteristics of the sites, and then compared the likelihood of being injured based on the different roadway characteristics. In this way, exposure was accounted for because all sites were similarly located along the cyclists' routes. Crashes that did not result in a hospital stay were not included in order to better focus on safety-related health outcomes. Dooring crashes were also not explicitly included or separately analyzed. This lack of dooring crashes presents a gap in the current literature. Because findings from past research suggest that, by increasing spacing, sharrows should help improve safety outcomes – especially in terms of dooring crashes – not including dooring crashes in a safety study means that one of the main hypothesized benefits is being excluded.

3. Data

In order to explore the relationship between sharrows and bicyclist safety outcomes, we examined Chicago block groups between 2011 and 2014 using bicyclist injury, exposure, and treatment data. We then examined the changes in bicyclist injuries both within the individual treatment typologies and between the treatment typologies.

The City of Chicago – through the Illinois Department of Transportation's Division of Traffic Safety – provided us with bicyclist injury data. This data included bicyclist injuries from both dooring and non-dooring crashes within the City of Chicago from 2011 through 2014. Bicyclist injuries were based on police reports submitted by law enforcement agencies. The reports provided crash locations for all injuries occurring on public property that were reported to and recorded by police. Severity of the bicyclists' injuries was not provided and was therefore not utilized in this study. We used injuries instead of fatalities because of the relative scarcity of bicyclist fatalities within the City of Chicago. Originally in spreadsheet format, we geocoded the injury data using ArcGIS and created a layer with each injury crash represented as one spatial point.

Beyond the typical absence of dooring crash data, another reason for the lack of sharrow safety research is inadequate bicycle exposure data. An ideal exposure metric would include bicyclist counts for every segment and intersection within the city and across the desired time frame. Unfortunately, no cities collect such extensive bicycling data, especially not on an adequately wide longitudinal time frame.

An alternative approach to accounting for bicyclist exposure is through bicycle commuter data from the American Community Survey (ACS). The underlying assumption that bicycle commuters are an indicator of total bicycling exposure has been shown by past research to be a reasonable assumption (Barnes and Krizek, 2005; Turner et al., 1997) and applicable for bicycle safety studies (Aultman-Hall and Kaltenecker, 1999; Marshall and Garrick, 2011; Chen et al., 2012). While not meeting the characteristics of an ideal exposure metric, ACS data allowed us to conduct this study with bicycle commuter counts on the block group level. These journey to work data (5-year compilations) and block group boundary layers were made available through the National Historical Geographic Information System (NHGIS) for each of the study years (Manson et al., 2017).

We then acquired bicycle treatment data from the City of Chicago Data Portal in ArcGIS format. Because this data did not include dates of installation, we dated the bicycle treatments by utilizing historic satellite imagery from Google Earth, historic Google Street View, Chicago bicycle maps, and communications with city planners. Installation years were identified for each roadway segment. Because we examined treatments implemented between 2011 and 2014, the available resources were able to provide the necessary precision.

There were considerable increases in the mileage of both bicycle lanes and sharrows in Chicago between 2011 and 2014 (Table 1). These bicycle lanes and sharrows were distributed throughout the city (Fig. 2). There were 1948 block groups within the city that had no bicycle treatments installed in 2012 or 2013, 42 block groups that had only sharrows installed, and 149 block groups that had only bicycle lanes installed. There were also 19 block groups that had both sharrows and bicycle lanes installed and 20 block groups that had bicycle lane upgrades (i.e. from standard to protected). Block groups that had both sharrows and bicycle lanes installed were not included in the analysis, as combining the two types of treatments may have resulted in a unique impact on safety. While these block groups could have been considered as their own category, their rarity (only nineteen out of 2178 block groups) precluded any statistical significance. Bicycle lane upgrade block groups were not included in the analysis as their inclusion could confound results.

4. Methods

After obtaining all necessary data, we operationalized bicycle treatments on the block group level by designating each 2010 block group as one of three types: (i) block groups that had no bicycle treatments installed in 2012 or 2013; (ii) block groups that had only sharrows installed in 2012 or 2013; or (iii) block groups that had only bicycle lanes (standard, buffered, and/or protected) installed in 2012 or 2013. We designated our 'before' period as 2011–2012 and our 'after' period as 2013–2014.

Using data on the block group level employs the assumption that the impacts of bicycle treatment installation are experienced throughout the entire block group. While this macro-scale approach limited the detailed exploration of the impacts of street design and other roadway characteristics, the methodology did allow us to accomplish a city-wide analysis on the block group level – a geographic level that has been shown to be effective for detecting differences in safety outcomes (Marshall and Garrick, 2010; Ferenchak and Marshall, 2017) – that included dooring data and bicyclist exposure.

We derived the number of bicyclist injuries in the before and after periods by spatially joining the injury point layer to the block group layer in ArcGIS. Because block groups are often delineated by roads, we avoided edge issues by utilizing a 50-foot buffer around each block group. In other words, if an injury occurred on the border between two block groups, we had that injury count for both block groups. We then joined the number of bicycle commuters in both the before and after periods for each block group from the ACS spreadsheets. In this way, every block group included a typology (bicycle lanes, sharrows, or

Table 1
Descriptive statistics for study block groups.

	N	Mean	SD	Min	Max
Bicyclist injuries					
2011–2012	3060	1.4	2.6	0	41
2013–2014	3174	1.5	2.6	0	40
Bicyclist commuters					
2011–2012	13,985	6.5	15.9	0	156
2013–2014	16,903	7.9	17.0	0	167

	Mileage (2011)	Mileage (2014)	Block groups
Sharrows	33.5	41.4	42
Bicycle lanes	122.1	157.0	149
Standard	122.1	131.6	n/a
Buffered	0	18.2	n/a
Protected	0	7.2	n/a
None	n/a	n/a	1948

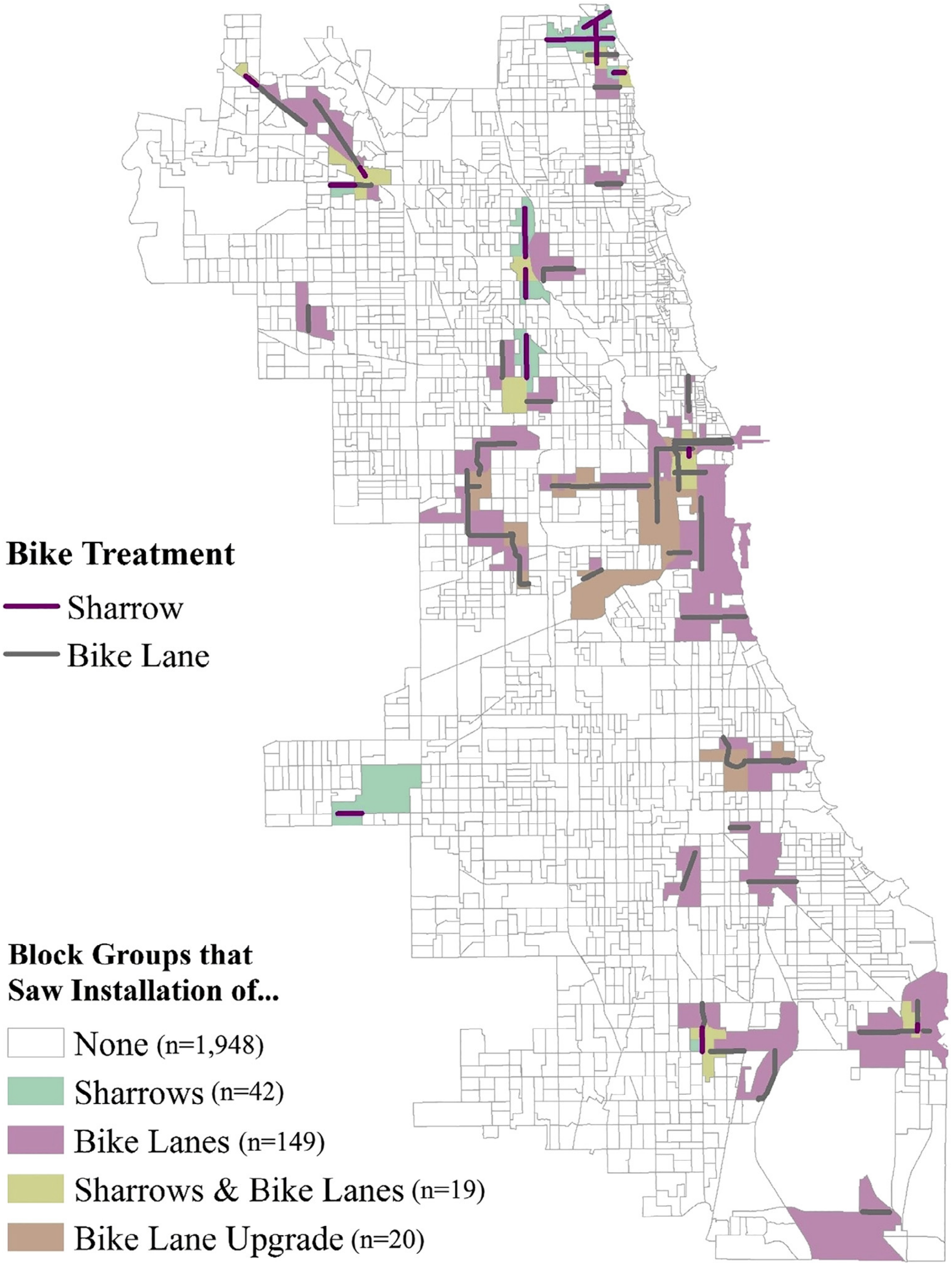

Fig. 2. Blocks groups with different bicycle treatments installed in 2012 and 2013.

none), the number of bicyclist injuries (both dooring and non-dooring) that occurred in the before period (2011–2012) and the after period (2013–2014), and the number of bicycle commuters in the before period and the after period.

Using the above data, we utilized negative binomial regressions to analyze the significance of the change in bicyclist injury counts over the study period within each individual treatment typology. Negative binomial regressions have been shown to be an appropriate approach when examining differences in macro-level and block group level bicyclist safety relative to changes in bicycle treatments (Wei and Lovegrove, 2012; Dumbaugh and Li, 2010). The negative binomial regression accounts for the overdispersion that we had in our data – and which is typically seen in traffic crash and injury data – and is the most appropriate and accepted practice for road safety researchers. We utilized the number of commuters and facility typology as independent variables and injury counts as the dependent variable in our models.

We then sought to compare the safety impacts of the different treatments in terms of injury rates. Because the analysis called for the comparison of the changes between pre- and post-installation scenarios for three different groups, a Kruskall-Wallis test was appropriate. This is a common approach for testing pre- and post-scenarios across multiple groups, especially in medical literature (Brennan et al., 1997; Ratcliffe et al., 2002; Şentürk et al., 2002). The Kruskal–Wallis test is a non-parametric one-way analysis of variance used to compare data when the data is not normally distributed. ANOVA was not used in this case because, although the differences among group rate means were being explored, the unbalanced sample sizes proved problematic for this type of statistical analysis, and the data did not fit the normal distribution (Shaw and Mitchell-Olds, 1993).

In order to complete the Kruskal–Wallis tests, we calculated bicyclist injury rates in the form of bicyclist injuries per 100 bicycle commuters. Because some block groups lacked bicycle commuters, we assumed one rider for null values in order to avoid artificial rate inflation and undefined values. We then weighted these rates based on the number of bicyclists in each block group. For instance, the injury rate of a block group with 100 bicycle commuters was given more weight in the overall average than a block group that had only 1 bicycle commuter. We used the margin of errors provided by the ACS in order to create confidence intervals around the rates. Using the Kruskal–Wallis test, we first compared bicyclist injury rates within individual treatment typologies and then compared the changes between the different treatment typologies.

5. Results

We first analyzed the number of bicycle commuters in relation to the type of treatment that was installed over the study period. Block groups with only sharrows installed had the largest increase in bicycle commuters (Table 2). Block groups that had no treatments installed had the smallest absolute increase in bicycle commuters. Both changes were significant at 95% confidence according to paired *t*-tests. Block groups that had bicycle lanes installed had the smallest percentage increase, although the change was not statistically significant.

5.1. Injuries within block group types

Negative binomial regressions allowed us to explore changes in bicyclist injury counts that occurred within the block group types for three categories of injuries: total injuries, dooring injuries, and non-dooring injuries (Table 3). Block groups that had no bicycle treatments installed and block groups that had sharrows installed saw decreases in total injuries, dooring injuries, and non-dooring injuries. All of these changes were found to be statistically significant. For block groups that had bicycle lanes installed, dooring injuries experienced a statistically significant decrease. However, overall injuries experienced a statistically significant increase. The change in non-dooring injuries in bicycle lane block groups was not statistically significant.

5.2. Injury rates within block group types

Ridership numbers for the different typologies enabled us to normalize bicyclist injuries and weight the injury rates to account for changes in ridership brought about by these treatments (Table 4). Kruskal–Wallis tests examined changes in injury rates within block group typologies between pre- and post-conditions. Because the bicycle lane block groups that had the smallest increases (or actually saw decreases) in injury rates had the most bicycle commuters (and were therefore weighted the heaviest), the overall injury rates in bicycle lane block groups saw the smallest percentage increase and the second smallest absolute increase (although these changes were not statistically significant). Similarly, block groups that had no bicycle treatments installed had their highest injury rate increases in block groups with relatively few bicyclists. This resulted in the smallest overall increase and second smallest percentage increase in overall injury rates (not statistically significant). Block groups that had sharrows installed had their largest injury rate increases occur in block groups that had the most riders. For this reason, the absolute and percentage increases in bicyclist injury rates were highest in sharrow block groups (statistically significant at 90% confidence). Dooring injury rates were reduced in block groups that had bicycle lanes installed (statistically significant at 90% confidence) and in block groups that had no bicycle treatments installed (not statistically significant), but dooring injury rates increased in block groups with sharrows (not statistically significant).

Table 2
Change in bicycle commuters for block groups with different types of bicycle treatments installed and corresponding paired *t*-test results.

		Bicycle commuters per block group				
	n	Before	After	Change	% change	*p*-value
None	1948	6.07	7.34	1.27	20.9%	0.000
Sharrow	**42**	**10.31**	**15.50**	**5.19**	**50.3%**	**0.032**
Bicycle lane	149	11.56	13.16	1.60	13.8%	0.224

Table 3
Negative binomial regression results for bicyclist injuries from before to after installation.

	n	*B*	Std. error	Sig.
None	1948	−0.275	0.0600	0.000
Dooring		−8.663	0.3550	0.000
Non-Dooring		−0.204	0.0638	0.001
Sharrow	42	−3.946	1.0188	0.000
Dooring		−13.074	2.0787	0.000
Non-Dooring		−6.143	2.4497	0.012
Bicycle Lane	149	5.416	1.7730	0.002
Dooring		−8.522	1.0761	0.000
Non-Dooring		0.057	0.1767	0.747

Table 4
Weighted safety rates for block groups with different types of bicycle treatments installed.

		Weighted injuries per year per 100 bicycle commuters				
	n	Before	After	Change	Change %	*p*-value
None	1948	8.70	9.75	1.05	12.1%	0.260
Dooring		1.82	1.40	−0.41	−22.5%	0.192
Non-Dooring		6.68	8.35	1.67	25.0%	0.041
Sharrow	42	8.97	18.28	9.31	103.8%	0.085
Dooring		1.34	4.23	2.89	215.7%	0.124
Non-Dooring		7.12	14.05	6.94	97.5%	0.121
Bicycle Lane	149	16.63	18.32	1.69	10.2%	0.986
Dooring		2.00	0.78	−1.22	−61.0%	0.053
Non-Dooring		14.53	17.54	3.02	20.8%	0.339

5.3. Injury rates between block group types

The Kruskal–Wallis test also allowed us to examine the difference in injury rate changes between typologies. Did injury rates increase more for bicycle lane, sharrow, or no-treatment block groups? Block groups that had bicycle lanes installed and those with no treatments installed saw a statistically smaller increase in bicyclist injury rates than sharrow block groups (Table 5). This relationship was significant at 95% confidence. Block groups that had bicycle lanes installed and block groups that had no bicycle treatments installed did not have significantly different changes in bicyclist injury rates.

Results suggest that in Chicago for the time period studied, block groups that had sharrows installed experienced poorer safety outcomes than those experienced by block groups that had bicycle lanes installed or that did not install any bicycle treatments. Block groups that had bicycle lanes installed saw the largest increase in bicyclist injuries between the before and the after periods while block groups that had sharrows installed saw a decrease in overall bicyclist injuries. However, after normalizing based on the increases in bicycle commuters, Chicago block groups that had bicycle lanes installed and those that had no bicycle treatments installed experienced similarly small increases in injury rates. This is in part because bicycle lane block groups with the largest increases in injuries had the fewest riders. Block groups that had sharrows installed experienced large increases in both the percentage change in injury rate and the absolute change in injury rate. This is because sharrow block groups that had decreases in injury rate had few bicycle commuters, while sharrow block groups that had increases in injury rate had many bicycle commuters. The increase in the bicyclist injury rate for Chicago block groups that had sharrows installed was statistically greater – with 95% confidence – than the increases experienced by bicycle lane block groups or those that had no treatments installed.

6. Conclusions

Improving bicycling safety barriers can enable more people to get on their bikes and thereby unlock considerable health benefits for those bicyclists (Fowler et al., 2017; de Hartog et al., 2010; Rojas-Rueda et al., 2011; Deenihan and Caulfield,

Table 5
Significance of Kruskal–Wallis test examining the longitudinal change in bicycle safety at 95% confidence.

Injuries per year per 100 bicycle commuters			
		Smaller increase in injury rate	
		Bicycle lane	None
Greater increase in injury rate	Bicycle lane	*n/a*	0.779
	Sharrow	0.050	0.004

2014). While bicycle treatments are a popular method of improving safety, not all bicycle treatments are equivalently effective (Harris et al., 2013). This work begins to fill an important gap in bicycle treatment research by investigating the safety impact of sharrows. As sharrows have become an accepted treatment in cities across the United States despite a lack of safety evaluation, this conversation has become a critical one. Our findings suggest that Chicago block groups that had sharrows installed experienced less than desirable safety outcomes for the study period. This paper finds that there is reason to further question the impact of sharrows on bicyclist safety outcomes through future research in other contexts.

While the mechanisms behind these findings are not yet understood and cannot be determined from this paper's results, one possible explanation is that the sharrows – as installed in Chicago during the study period – provide a false sense of security to bicyclists (Hunter et al., 2000). When a bicycle lane or other separated facility is provided, the bicyclist is granted dedicated space. This dedicated space lowers the risk of collision with a motor vehicle (Khan and Langlois, 2011). Alternatively, if bicycle treatments are not provided on a roadway, it is understood that the bicyclist will need to share the travel lane with vehicles (Landis et al., 1997). The bicyclist should therefore ride in a manner appropriate to the level of risk created by the volume, speed, and other characteristics of the roadway. When a sharrow is provided, however, bicyclists may believe that they are at lower risk because a treatment is being provided and change their behavior accordingly. Furthermore, new bicyclists – possibly less experienced ones – may be attracted to the facility. While the operations (e.g. lateral spacing) of vehicles and bicycles may be altered by the presence of the sharrow, those operational changes may not necessarily lower the probability of a collision with a motor vehicle. Might there be situations in which moving a bicyclist further in or out of a lane does not make them objectively safer? While subjective safety may be improved, objective safety may remain static, thus resulting in poor safety outcomes. Researchers have shown that adding crosswalks without treating underlying safety issues may give pedestrians a false sense of security and result in increased pedestrian crash rates (Herms, 1972; FHWA, 2005). Might sharrows be inducing the same phenomenon for bicyclists? Obtaining clarity on this issue will require further street-level research.

The methodologies employed throughout this paper use a number of assumptions, the validity of which should be explored in future research. First, this research employed the assumption that the impact of bicycle treatment installation

Fig. 3. Examples of alternative forms of sharrows (clockwise from top-left): Portland's Sharrow Flower, a diagonal wayfinding sharrow, Long Beach's Green Sharrow, and an intersection sharrow. Photo Credit: Michael Anderson, NACTO, San Francisco Bicycle Coalition, and Eric Fischer

will be experienced throughout the block group within which the treatment is installed. This assumption was used primarily so that we could perform analysis on the block group level, which allowed for the bicycle commuter metric to be utilized for exposure. While it would be ideal to longitudinally examine specific corridors that had sharrows installed, this would have required ridership counts specific to those corridors, which was not feasible based on the size of the study and the lack of preexistent bike count data. A further limitation of the bicycle commuter data that we used to represent exposure is that the data only considers the origin of the commute trip, not the destination or the path that the commuter uses. It may be that a commuter lives on the edge of their block group and does not ride through the block group that they live in. That being said, bicycle commuter counts have been shown to be a reasonable indicator of total bicycling exposure (Barnes and Krizek, 2005; Turner et al., 1997) and to be applicable for bicycle safety studies (Aultman-Hall and Kaltenecker, 1999; Marshall and Garrick, 2011; Chen et al., 2012).

In future corridor-level work, the amount of bicycle treatments could be accounted for in order to directly determine the strength of the relationship between sharrows and bicyclist safety, as opposed to the inter-typology comparative approach of this work. Accounting for injury severity in future work may further inform the relationship that sharrows have with bicyclist safety. Furthermore, future studies might benefit from the incorporation of demographics or socio-economic data into their models. Demographic and socio-economic factors have been shown to be correlated with bicycle ridership and traffic safety outcomes. Inclusion of these factors may allow for a more robust model and a better understanding of the complexity of these issues.

The implications of this work help contribute toward the goal of bettering traffic safety outcomes within our cities. The objective of this research was to identify bicycle treatments that are effective at improving bicyclist safety. The results of the analysis indicate that we may need to further examine exactly where and when sharrows should be used. As part of this, it may be useful to remember that sharrows are signage and not actual bike infrastructure. Under current standards and guidance, sharrows can be used for a wide variety of reasons and in a wide variety of roadway conditions: from wayfinding devices to lateral spacing guides and from local roads to arterials. Researchers have not explored all of the different combinations in which sharrows can and are being used. This paper does not claim to inform any of these specific scenarios but broadly identifies one case study in which safety improvements seem to be lacking. Fig. 3 shows some examples of the wide variety of shapes, sizes, and forms in which sharrows have appeared. This work strictly evaluated the effectiveness of the MUTCD version of the sharrow that was used in Chicago, but future work that explores different sharrow shapes, sizes, forms, functions, and roadway scenarios would be warranted.

With sharrows becoming a familiar sight on our roadways and the health benefits of bicycling becoming clearer, it is vital to fully understand the impact that sharrows have on bicyclist safety. While past research has identified the relationship between sharrows and operational metrics such as lateral spacing, it is only a theoretical means to an end. The effectiveness of sharrows in terms of the true goal, which is reducing bicyclist injuries and fatalities, remains unclear in the current body of research. This work begins to question their effectiveness and should act as a call for more research on the subject. It is imperative that appropriate treatments are in place to ensure the safety of all users on our roadways to thereby enable the substantial health benefits that stand to be gained. It remains to be seen what role sharrows play in this pursuit.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijtst.2018.12.003.

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