sustainability

MDPI

Article

Safety and Nonoptimal Usage of a Protected Intersection for Bicycling and Walking: A Before-and-After Case Study in Salt Lake City, Utah

Torrey Lyons [1], Dong-ah Choi [2,*], Keunhyun Park [3] and S. Hassan Ameli [2]

[1] Department of City and Regional Planning, University of North Carolina at Chapel Hill, New East Building, CB3140, Chapel Hill, NC 27599, USA; torrey.lyons@gmail.com
[2] Department of City and Metropolitan Planning, University of Utah, 375 South 1530 East, Suite 220, Salt Lake City, UT 84112, USA; hassan.ameli@utah.edu
[3] Department of Landscape Architecture and Environmental Planning, Utah State University, 4005 Old Main Hill, Logan, UT 84322, USA; keunhyun.park@usu.edu
* Correspondence: dongah.choi@utah.edu; Tel.: +1-801-831-8019

Received: 28 September 2020; Accepted: 2 November 2020; Published: 5 November 2020

check for updates

Abstract: This paper describes a before-and-after case study of a protected intersection in Salt Lake City, Utah. The intersection was completed in late 2015 and represented one of the first examples of a protected intersection design in North America. We analyzed bird's-eye view video data that was recorded before the intersection was implemented and compared it against video data recorded from the exact same location after implementation. In order to examine changes in intersection usage and behavior, we operationalized safety in terms of the frequency of nonoptimal behaviors demonstrated by active transportation modes. We found that active transportation usage of the intersection has increased since the new configuration, with most of that growth attributable to e-scooter users. There was minimal change in the rates of nonoptimal behaviors by pedestrians. Bicyclists showed mostly decreased rates of nonoptimal behaviors, suggesting improved safety for this mode. E-scooter users, however, demonstrated nonoptimal behaviors at very high rates as compared with other active modes. This case study gives evidence that a protected intersection can have positive effects on active transportation volume and safety in a U.S. context.

Keywords: protected intersection; direct observation; quasi-experimental design; natural experiment; e-scooter; behavioral research

1. Introduction

As a sustainable urban transport mode and important type of physical activity, bicycling has been recognized to provide various health benefits, including a reduction in the risks of diabetes, heart disease, obesity, cancers, and an increase in metabolic and cardiorespiratory functions [1–4]. In the past few decades in the USA, bicycle trips have increased significantly through the addition of new infrastructure and a general increase in attention given to active transportation [5,6]. However, as increased bicycle usage involves increased conflicts between bicyclists, pedestrians, and motor vehicles, creating safe environments for active transportation and physical activity has been a critical mission of planners. Whether streets incorporate bicycle lanes is one of the most significant environmental factors that promotes cycling behaviors and decreases bicycle crashes [3,7]. As governments develop a wide variety of bicycle-friendly infrastructures and programs [5], an important research question is whether, and to what extent, each intervention impacts bicycling and road safety.

Protected intersections are one of the novel infrastructure designs that incorporates many of the following attributes of successful European designs: physically separating rights of way, making pedestrians and bicyclists more visible to drivers, providing shorter crossing distances for active transportation users, and prioritizing active modes through signalization. These intersection treatments are relatively new to North American cities, and there are only a handful of protected intersections in North America [8]. While there are differences in design features among the existing protected intersections, Salt Lake City's design is understood to be the best example of an intersection that incorporates the most aspects of the adapted North American typology [8]. However, to date, no studies have empirically investigated the impact of protected intersections on cycling and other users' behaviors in the U.S. context.

This study utilizes before-and-after video analysis to examine the effects of the implementation of a protected intersection on safety and usage by pedestrians, cyclists, and other active users. The study site is the signalized intersection at 200 West 300 South of Salt Lake City in Utah, which was completed in its current form in 2016. With video data of the intersection taken in 2015, 2016, and 2018, we focus on two outcomes, i.e., changes in intersection usage and changes in nonoptimal behavior. First, we identified how many people used the intersection and how the figures have changed since the new intersection was introduced. Second, we investigated the proportion of people who did not comply with safe utilization of the intersection and examined whether the nonoptimal behavior rates have changed since the new intersection was introduced.

This study is the first of its kind for a U.S. protected intersection, and its insights should help to guide active transportation infrastructure design and public-health practices in the future. Leading researchers in bicycle and pedestrian planning have written at length about the lessons that can be learned from European traffic designs, and practitioners have adapted those designs to conform to an American context. We know a fair amount about the effects of these traffic configurations from studies that have examined them empirically, however, it cannot necessarily be assumed that the findings are generalizable to the North American context. Our in-depth case study on a protected intersection should bring critical insights that help researchers and practitioners to better understand the effects of intersection design changes in the U.S. context.

2. Literature Review

When active transportation planning first came to the fore in North America, planners looked to European cities for insight into how to create more hospitable environments for pedestrians and bicyclists. Policies that can help make active transportation more appealing than automobiles often include gasoline or carbon taxes, high registration fees for vehicles, and other economic disincentives [9,10]. Such policies, however, might be considered to be untenable within the context of American politics. If the stick is not a viable option for U.S. planners and policymakers, what about the carrot? Pucher and Buehler [11] looked to European examples and found that, beyond automobile restricting policies, countries such as the Netherlands, Denmark, and Germany relied on ubiquitous provision of safe infrastructure for bicyclists and pedestrians in order to enhance the attractiveness of these modes. European cities have long provided for safe integration of bicyclists and vehicles through the use of special signalization, physical separation, advanced stop location for bicyclists, and other designs that facilitated safe use of streets among multiple modes of transportation [12]. Researchers have found that physical and visual separation of automobile and bicycle rights of way improved the perceived safety of active transportation and have led to increased usage [3,11,13–15]. Additionally, the benefits of investment in active transportation infrastructure have been shown to far exceed the costs. Gotschi [16] determined that an investment of bicycles of USD 605 million, in Portland, OR, would result in health care savings of USD 594 million, fuel savings of USD 218 million, and value of statistical lives of USD 12 billion over a 50 year period.

Through the addition of new infrastructure and a general increase in attention given to active transportation in the past few decades in the USA, bicycle trips have more than doubled [5,6]. While this represents a terrific realization of the efforts of planners to enhance the environment for active transportation, it also presents a new opportunity for increased conflicts between bicyclists, pedestrians, and motor vehicles. Motor vehicles, on their own, are immensely dangerous, with motor vehicle crashes being a leading cause of death globally, and among the top ten most prominent causes of death among young people nationally [17,18]. The best estimates of pedestrian-vehicle crashes suggest that there are more than 100,000 of these types of incidents per year in the USA, with nearly 5000 of them resulting in a fatality [19,20]. Although there is always potential for conflict among automobiles, bicyclists and pedestrians, the likelihood of a collision is far greater at intersections, where all modes interact using much of the same space [21–23]. In fact, a study of 15 years of crash data in Palo Alto, CA, found that nearly three-quarters of crashes involving cyclists and motor vehicles occurred at intersections [22]. For this reason, much of the literature on safe design for bicycles and vehicles has focused on behavior at intersections [24–28]. There has also been a tendency to study crash history, as longitudinal data have some advantages in their ability to imply causation. Unfortunately, however, these studies are limited because their design necessitates decades worth of data [28–30].

There are many design features that have been developed in hopes of creating a safer environment for the interaction of pedestrians, bicyclists, and vehicles. Colored markings are one of the simplest and most cost-effective methods used for delineating the respective spaces for bicycles and automobiles [31]. Colored markings through intersections demand even more attention from roadway users and have been shown to decrease intermodal crash rates in both European and American contexts [32,33]. Bicycle boxes, or protected areas where bicycles safely enter and stop in an advanced position in an intersection in front of automobiles, are intended to make bicyclists more visible to drivers. However, limited research has shown that this design provides scant evidence for increased safety. Hunter [33] found little reduction in conflicts between automobiles and bicycles and a significant amount of encroachment into the bicycle box by vehicles. New methods for traffic signalization have also been employed in an attempt to improve safety at intersections. Scramble signals allow bicycles and pedestrians to move freely in all directions while automobiles are restricted from entering the intersection. Bicycle-only directional signal phasing also restricts automobiles from entering the intersection while bicycles and pedestrians are permitted, but they also limit the movements of active users for increased safety. The methods have both been shown to improve the safety of intersections by reducing the number of conflicts between bicyclists and vehicles [21,34]. Increases in intersection usage by active transportation modes have also been attributed to scramble signals [34]. Finally, as these methods make intersections more appealing to active transportation users, simply the increased number of pedestrians and bicyclists using the intersection makes the environment safer for those modes. Jacobsen [35] found that motorists were less likely to collide with pedestrians and bicyclists when more of these users were present.

Although the above findings help planners and traffic engineers determine what treatments might improve safe integration of all modes of transportation at intersections, there remains a significant amount of knowledge yet to be discovered. Many European cities such as Copenhagen and Amsterdam have developed intricate systems of protected bicycle lanes and intersections that employed many of the methods we have discussed for creating safer intersections. However, studies of these intersections are limited in number, and confounding the situation further is the fact that findings from studies of European designs in European contexts might not be applicable in a North American context. There is a dire need, therefore, for studies that examine the effects of protected intersection treatments in the USA. This study examines the best American example of a protected intersection to date, using before-and-after video analysis of pedestrian, bicycle, vehicle, and other users in the intersection.

3. Research Design

This study employs a before-and-after case study, also called quasi-experimental design or natural experiment. While there have been studies of foreign examples of new intersection designs [36,37], the findings from these studies might not necessarily be applicable to an American context [21]. Salt Lake City's 200 West 300 South intersection is the best example of the modern protected intersection design among the twelve that currently exist in the USA. Thus, a longitudinal analysis of this example should help researchers and practitioners better understand the effects of intersection design changes in the U.S. context.

3.1. Operationalizing Safety and Tested Hypotheses

Safety is a relatively nebulous construct that has been measured in countless ways throughout the vast transportation planning and engineering literature. A common way to measure safety is the incidence or frequency of collisions. This measure is effective when considering the safety of a traffic corridor, traffic analysis zone, or larger geography over time. However, when we refine the spatial or temporal scale to a single intersection at a given moment, crash rates become too infrequent to provide meaningful analysis. The availability of unique high-quality video data taken over three different points in time provides us an opportunity to measure safety in a completely novel way with greater detail and nuance.

For the purposes of this study, we are operationalizing safety as the prevalence of what we call "nonoptimal behaviors". Optimal behaviors are considered to be behaviors by people who conform to the expected use of given lanes at the protected intersection, and thus prevent possible conflicts (Figure 1). Thus, it can be assumed that if road users are changing their behavior to a higher degree of conformity than the expected optimal behaviors, the examined area will be a safer place for road users. Thus, in this study, nonoptimal behaviors are defined as any behaviors that are deviant to the optimal behaviors. This is different from illegal traffic maneuvers because not all dangerous intersection movements are necessarily illegal. Protected bicycle intersections, for example, are designed to reduce the amount of space and time that pedestrians and cyclists are exposed to vehicular traffic. This design, in part, is intended to facilitate safer left turn movements of cyclists by allowing them to cross the intersection straight ahead, wait for the next signal phase in a protected bike box, and then cross again straight ahead. Making a left turn in this way greatly reduces the risk to cyclists of colliding with a vehicle by reducing their exposure to oncoming vehicles. However, making an exposed left turn is not illegal for cyclists. This is the best example of the difference between an illegal maneuver and a nonoptimal behavior.

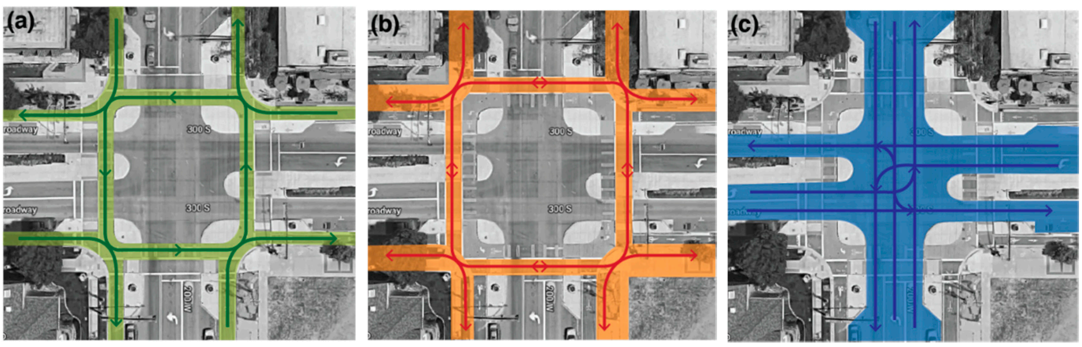

Figure 1. Optimal behaviors at the protected intersection by mode: (**a**) bicyclists ride in bike lanes (**b**) pedestrians walk on sidewalks and crosswalks (**c**) motorists drive in vehicle lanes.

We contend that the frequency of nonoptimal behaviors is an effective proxy for safety, especially when studying the interaction of multiple transportation modes at a protected intersection. Over the three-year study period, there were only four reported traffic collisions near the intersection. The infrequency of this event and the lack of detail related to the cause of the collision gives us little information about how the configuration of the intersection is leading to safety for active transportation users. For this reason, we propose nonoptimal behavior as an effective measure of safety for analyzing a protected intersection.

In this study, we test two hypotheses. First, the implementation of a protected intersection promotes active transportation usage. The protected intersection design physically separates cyclists and pedestrians from cars, where we expect active transport users to feel more comfortable using the intersection area, and thus their usage will increase. Second, the implementation of a protected intersection reduces the rates of nonoptimal behaviors of active transport users. The protected intersection provides more exclusive places for individual types of active transport users, in which we expect fewer conflicts and fewer nonoptimal behaviors.

3.2. Data Collection and Processing

We obtained video records of intersection usage from the Salt Lake City Transportation Division. Salt Lake City had collected a total of 36 h of video data. These data came from 12-h segments taken on the following three separate days: 31 July 2015 (before), 19 August 2016 (after 1), and 24 August 2018 (after 2) (Figure 2). Each video was recorded under particular controlled conditions, i.e., taken for 12 h (7:00 to 19:00) at the same place, on the same day of the week (Friday), in the same time of the year (July or August), in similar weather conditions.

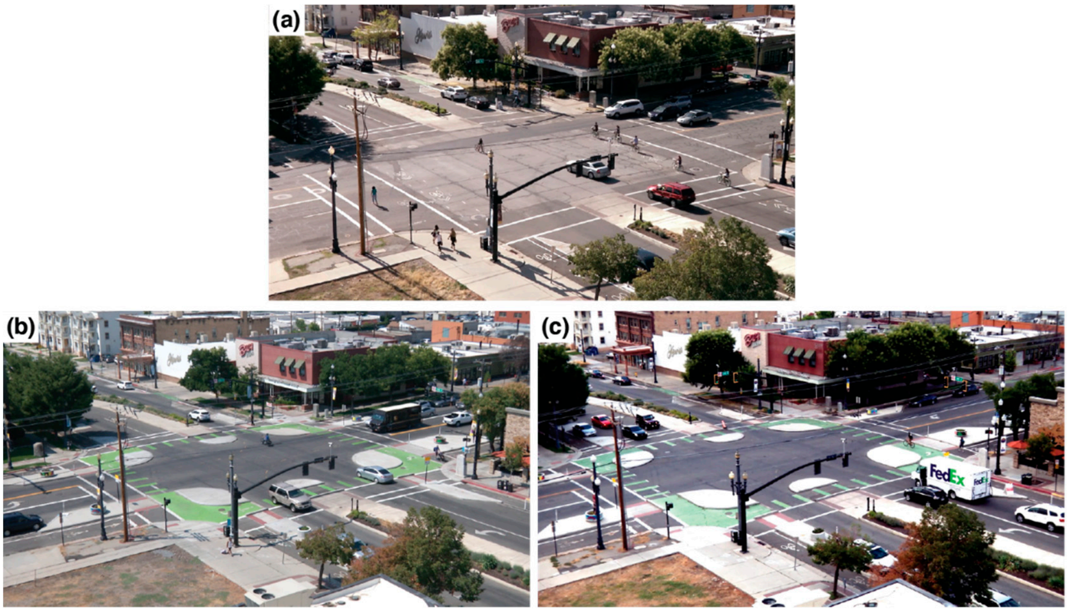

Figure 2. Screenshots of video records: (**a**) pre-implementation on 31 July 2015 (**b**) post-implementation on 19 August 2016 (**c**) post-implementation on 24 August 2018.

We divided the video analysis into two separate tasks (see Figure 3). First, we counted intersection users, segmenting counts by mode of travel. We ran the video at a faster than real-time speed to expedite the analysis for this task. We analyzed all twelve hours of video for each day, and recorded counts by the hour. Second, we counted nonoptimal behaviors and calculated the nonoptimal behavior rates to the total counts. This required running the video at near real-time playback speeds with frequent pausing and rewinding to ensure that behaviors were identified correctly, and nothing was missed. Because this process was so intensive, we sampled three one-hour segments (09:00–10:00, 13:00–14:00, 17:00–18:00) for each observation day. We chose these times specifically because they were the peak periods for active transportation usage, based on our preliminary analysis of activity in the intersection.

We also included vehicle traffic data in our analysis, however, measured at a courser scale of geography. We included annual average daily traffic (AADT) for one of the roads in the intersection, as well as crash data provided by the Utah Department of Transportation. These data provided useful insight into how the new intersection configuration had affected vehicle traffic and safety. This is useful context as we discuss active transportation usage and safety.

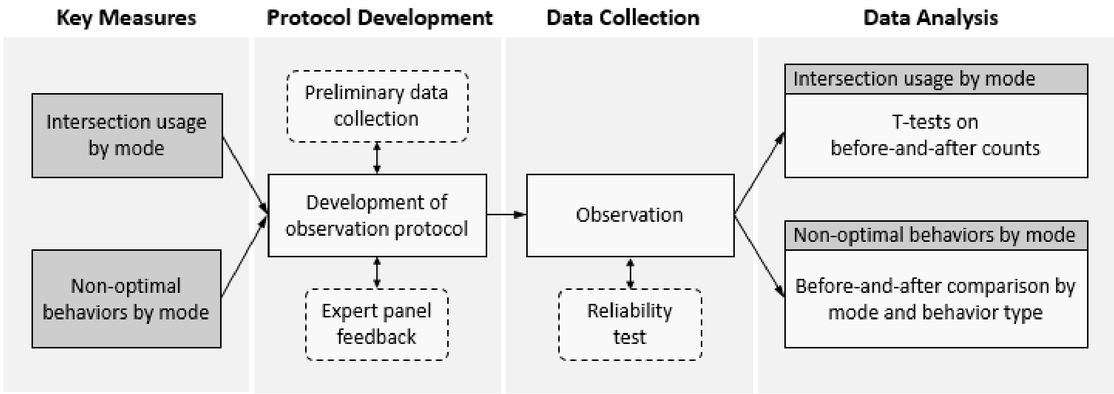

Figure 3. Data collection and analysis process.

3.3. Types of Nonoptimal Behaviors

Although counting the number of intersection users is quite straightforward, as noted in the previous section, identifying and counting nonoptimal behaviors is challenging. Thus, to increase the precision of the work, a pilot study was conducted, in which we identified a total of 19 nonoptimal behaviors at the intersection, seven for bicyclists, five for pedestrians, and seven for others (Table 1). Examples included walking on bikeways, riding a bike in the opposite direction on bikeways, and disobeying signals. First, as each user approached the intersection, we examined the number of users moving outside the correct lanes. Second, as each user turned or crossed the intersection, we counted the number of users crossing outside the correct crossing lanes, disobeying signals, or riding a bike in the opposite direction. Lastly, as each user stopped at the intersection, we investigated the number of users standing in wrong places. Figure 4 shows screenshots of examples of nonoptimal behaviors. Our assumptions, with respect to what constituted nonoptimal behavior, were based on our expertise in traffic safety and local and national policy. Additionally, our decisions for categorizing nonoptimal behaviors were made with the input of an external expert panel consisting of practicing planners and engineers.

Table 1. Types of nonoptimal behaviors.

Mode	Behavior Group	Nonoptimal Behavior	Description
Bicycle	Approaching	Riding on sidewalk	Bicycle riding at least 15 ft in sidewalk
		Riding on street	Bicycle riding at least 15 ft along the roadway, except crossing on street
	Turning/crossing	Clockwise ride/wrong direction in intersection	Bicycle riding/turning in a wrong direction in bike lane
		Crossing in crosswalk	Bicycle crossing in any direction in crosswalk
		Crossing in street	Bicycle turning in street (exposed and non-protected area) (e.g., riding roadways at intersection)
		Disobeying signal	Bicycle crossing intersection against car movement
	Stopping	Stopping in wrong place	Bicycle stopping in sidewalk, roadway, and other places that are not bike lane
Pedestrian	Approaching	Walking on street	Pedestrian walking at least 15 ft along the roadway, except crossing on street
		Walking on bike Lane	Pedestrian walking at least 15 ft on the bike lanes, except crossing the intersection)
	Turning/crossing	Crossing outside crosswalk	Pedestrian crossing in roadway and bike lane
		Disobeying signal	Pedestrian crossing intersection against the "Don't Walk" (or Red Hand) signal
	Stopping	Stopping in wrong place	Pedestrian stopping in roadway and/or bike lane

Table 1. *Cont.*

Mode	Behavior Group	Nonoptimal Behavior	Description
Others (scooter, skateboard, segway, etc.)	Approaching	Riding on sidewalk	Other using at least 15 ft in sidewalk
		Riding on street	Other using at least 15 ft along the roadway, except crossing on street
	Turning/crossing	Clockwise ride/wrong direction in intersection	Others turning in a wrong direction in bike lane
		Crossing in crosswalk	Others turning any direction in crosswalk
		Crossing in street	Others turning in street (exposed and not-protected area) (e.g., riding roadways at intersection)
		Disobeying signal	Others crossing an intersection against cars movement
	Stopping	Stopping in wrong place	Others stopping in sidewalk or roadway

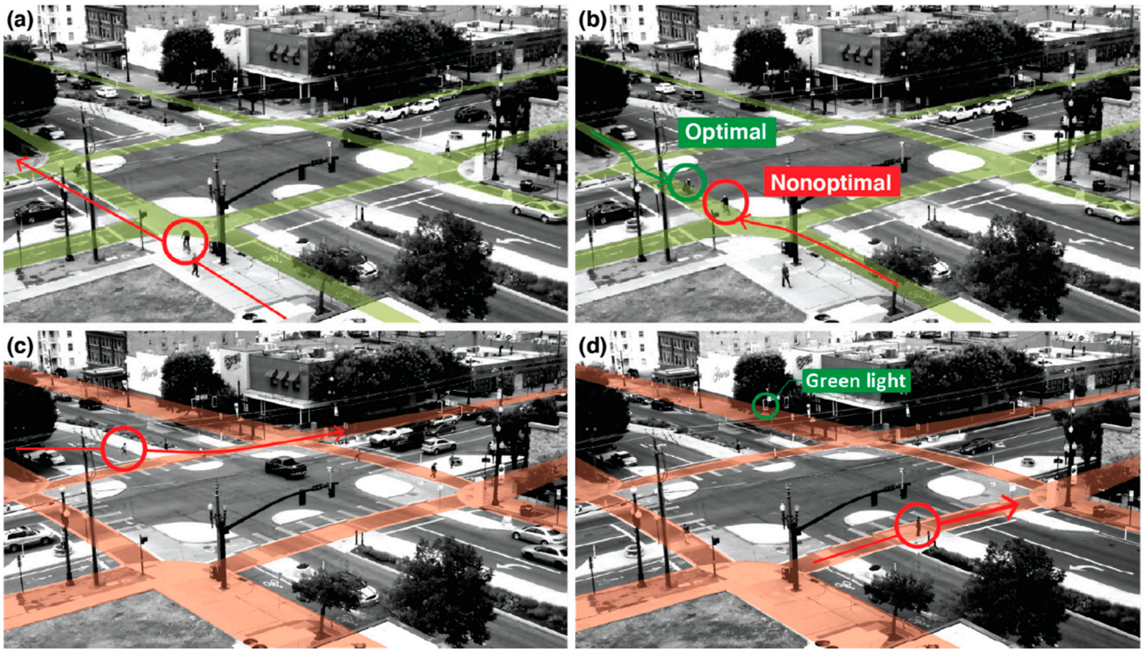

Figure 4. Screenshots of examples of nonoptimal behaviors: (**a**) Bicyclist riding on sidewalk (**b**) Bicyclist crossing clockwise (**c**) Pedestrian crossing outside crosswalks (**d**) Pedestrian disobeying signal.

3.4. Reliability of Observation

We tested inter-rater reliability, also called inter-observer reliability or inter-rater agreement, for the following two types of data: (1) total counts by transportation mode and (2) counts by each nonoptimal behavior type. The intraclass correlation coefficient (I.C.C.) is an appropriate measure of inter-rater reliability and has been used in behavioral research [38–40]. The I.C.C. measures the extent of agreement between two or more raters for continuous variables. Higher I.C.C. values indicate greater reliability, with an I.C.C. estimate of 1 indicating perfect agreement, 0 indicating only random agreement, and a negative I.C.C. indicating systematic disagreement.

According to Cicchetti [41], inter-rater reliability should be considered poor for I.C.C. values less than 0.40, moderate for values between 0.40 and 0.59, good for values between 0.60 and 0.74, and excellent for values greater than 0.75. Following the guideline from Koo and Li [39], we used a "two-way mixed model" because raters were fixed, and our subjects were chosen randomly and measured "absolute agreement" rather than consistency. The I.C.C. values were computed in R 3.6.0 software (psych package).

A fifteen-minute video segment was used as a unit of analysis for the reliability test. The minimum sample size for three raters with ICC 0.5 minimum, power 80%, and alpha 0.05 is 11 [42]. Thus, three observers watched the same 11 fifteen-minute video segments and counted bicycles, pedestrians, and other types of modes (e.g., scooter, skateboarders, segways, etc.) for each nonoptimal behavior type.

Table 2 shows that the inter-rater reliability of total counts is excellent for all modes of transportation in the observed intersection. Table 3 also illustrates that the reliability of nonoptimal behaviors is considered to be excellent by mode, with I.C.C. values from 0.84 for pedestrian to 0.94 for other users (scooter users, etc.), but there are greater differences in reliability by behavior type. When coded by each behavior type, 18 of the 19 categories had one or more incidences in the sample video clips, one category, "other modes crossing in street", was not observed by any rater, as was rarely found in our observation result. Out of 19 categories, 10 categories were considered to be in an excellent reliability range (ICC > 0.75), three in a good reliability range (0.60 < ICC < 0.75), and four in a fair range (0.40 < ICC < 0.60). One category that reported a poor I.C.C. value (less than 0.40) was "bicycle stopping in wrong place" (I.C.C. = 0.32). Thus, data for these low-reliability categories would need careful interpretation.

Table 2. Inter-rater reliability test results of total counts by transportation mode.

Category	Average Number of People Per Hour			I.C.C.
	Rater 1	Rater 2	Rater 3	
Bicycle	37.78	32.67	37.69	0.85
Pedestrian	203.06	189.08	200.97	0.95
Other (scooter)	11.47	11.33	9.86	0.99
Total	252.31	233.08	248.53	0.95

Table 3. Inter-rater reliability test results of counts by nonoptimal behavior.

Mode	Behavior Group	Nonoptimal Behavior	I.C.C. (by Mode)	I.C.C. (by Behavior Type)
Bicycle	Approaching	Riding on sidewalk	0.91	0.87
		Riding on street		0.84
	Turning/crossing	Clockwise ride/wrong direction in intersection		0.60
		Crossing in crosswalk		0.94
		Crossing in street		0.62
		Disobeying signal		0.62
	Stopping	Stopping in wrong place		0.32
Pedestrian	Approaching	Walking on street	0.84	0.49
		Walking on bike Lane		0.50
	Turning/crossing	Crossing outside crosswalk		0.78
		Disobeying signal		0.83
	Stopping	Stopping in wrong place		0.43
Other (scooter, skateboard, Segway, etc.)	Approaching	Riding on sidewalk	0.94	0.93
		Riding on street		0.50
	Turning/crossing	Clockwise ride/wrong direction in intersection		0.88
		Crossing in crosswalk		0.87
		Crossing in street		N.A.
		Disobeying signal		0.98
	Stopping	Stopping in wrong place		0.81

3.5. Statistical Analysis

To identify changes in behavior from before the protected intersection implementation and after, we employed the difference of means tests and descriptive statistics. The application of inferential statistics to our data depends on the sample size and number of observations that we have available. On the basis of these constraints, we only applied t-tests to intersection usage data. For nonoptimal behavior measurements, we used descriptive statistics. This meant that the observations of changes in nonoptimal behavior were simply descriptive, and we could not say that the intersection implementation led to statistically significant changes.

4. Results and Discussion

4.1. Intersection Usage

Table 4 displays changes to intersection usage as estimated by video data counts of different modes. We calculate change as the difference between the average of the two post-implementation sample periods (2016 and 2018) from the pre-implementation period (2015). The exception to this method is the calculation of the change in the "other (scooter only)" category, which is measured as the difference between the average of the two days of video (August 2015 and 2016) before the deployment of shareable scooters in the summer of 2018 and the one post-deployment, as well (August 2018).

Table 4. Intersection usage.

Mode	Year			Change	t-Statistic [b]
	2015	2016	2018		
Bicycle	431	457	409	1.8	−0.04
Pedestrian	2379	2327	2412	−9.3	0.08
Other	21	21	350	164.5	−5.95 **
Other (scooter only)	5	2	339	335.8 [a]	5.63 **
Total	2831	2805	3171	157	−1.06

Note: The data come from 12-hour segments, one day each year. All counts are averages using data assessed by three observers. Except for other (scooter only), all numbers in the change column show the difference between 2015 and the average of 2016–2018, in order to show the before-and-after changes related to the implementation of the protected intersection. [a] Change column for other (scooter only) shows the change between the average of 2015–2016 and 2018, because e-scooter sharing systems began in 2018. [b] ** $p < 0.01$ and * $p < 0.05$.

In total, we found an increase of 157 additional non-motorized users of the intersection after the implementation of the new protected intersection configuration, per the two days of video data analyzed. This is a modest increase, with the greatest growth in usage happening between 2016 and 2018. Interestingly, we see little change in bicycling and walking usage from before and after the implementation of the protected intersection. Most notably, almost all the growth in active transportation usage of the protected intersection between 2016 and 2018 is attributable to an increase in e-scooters. This mode demonstrates 336 more scooters between 2015–2016 and 2018 ($p < 0.01$).

4.2. Nonoptimal Behavior

Table 5 displays measures of nonoptimal behavior among all active transportation modes. To calculate the rate of nonoptimal behaviors, we divided the counts of behaviors by the estimated usage counts from the previous analysis. We recorded the travel mode volume estimates by the hour, so the volumes were aggregated from the 09:00–10:00, 13:00–14:00, and 17:00–18:00 segments, corresponding to our nonoptimal behavior sample times.

Some patterns can be observed in nonoptimal behaviors among bicyclists after the implementation of the protected intersection. Bicyclists crossing the intersection in the crosswalk declined from a pre-implementation rate of 17.1% to a post-implementation average of 6.2%. This is likely due to the improved painted pavement that makes the area where bicyclists are expected to cross the intersection much clearer than in the previous configuration. Bicyclists also demonstrated a decrease in the rates of exposed left turns after the implementation of the protected intersection. This came as somewhat of a surprise, because we expected the optimal movement for a left turn, which required that a bicyclist travel straight across the intersection, then wait for another signal change, and then travel straight across again, to be too onerous to elicit an observable change even with the new configuration. This was not the case, however, and the rate of exposed left turns declined from 17.1% to an average of 2.5%.

Table 5. Rates of nonoptimal behaviors.

Behavior			**2015**	**2016**	**2018**
Traveler	Behavior group	Nonoptimal behavior	per user %		
Bicyclist	Approaching	Riding on sidewalk	11.7	8.0	12.2
		Riding on street	7.2	5.6	7.8
	Turning/crossing	Clockwise ride/wrong direction in intersection	5.4	10.4	7.8
		Crossing crosswalk	17.1	7.2	5.2
		Crossing street	17.1	2.4	2.6
		Disobeying signal	5.4	8.0	12.2
	Stopping	Stopping in wrong place *	16.2	3.2	2.6
Pedestrian	Approaching	Walking on street	0.3	0.2	0.6
		Walking on bike Lane	0.0	0.3	0.5
	Turning/crossing	Crossing outside crosswalk	6.1	2.1	5.6
		Disobeying signal	9.6	9.2	11.6
	Stopping	Stopping in wrong place	3.1	0.0	0.9
Other (e.g., scooter, skateboard, segway)	Approaching	Riding on sidewalk	-	-	43.2
		Riding on street	-	-	5.3
	Turning/crossing	Clockwise ride/wrong direction in intersection	-	-	12.6
		Crossing in crosswalk	-	-	22.1
		Crossing in street	-	-	3.2
		Disobeying signal	-	-	16.8
	Stopping	Stopping in wrong place	-	-	4.2

Note: The data from three one-hour segments (09:00–10:00, 13:00–14:00, and 17:00–18:00), in each of the three daily, August counts. All numbers were reported by one observer who used a reliable observation protocol. We did not report nonoptimal behaviors rates for the "other" category prior to the 2018 observation because the small number of observations contributed to misleading measures. However, the value of 2018 "other" data was found to make a comparison with nonoptimal bicycling behaviors. An asterisk mark (*) indicates nonoptimal behaviors with a poor I.C.C. value.

Bicyclists also demonstrated lower rates of stopping in incorrect positions after the implementation of the protected intersection. We attribute this improvement to the clearer delineation of space for stopped cyclists in an area known as the "bike box." This area is painted a different color than the other pavement and is also physically separated from the street, likely leading to an increased feeling of safety for bicyclists waiting for the changing traffic signal (Figure 1). There was one nonoptimal behavior that increased significantly after the protected intersection was implemented, i.e., bicyclists not obeying the signal and crossing against the movement of cars. This presents potential safety concerns as bicyclists are vulnerable to being hit from the side by a car traveling perpendicular to the direction of their travel. We suggest that this change is likely due to the reduction in travel lanes, and thus the shorter distance the bicyclist must traverse across the intersection while being exposed to motorized traffic.

Pedestrian behavior did not change in a way that provided many observable patterns. The change in nonoptimal behavior of this mode was small and did not seem to fluctuate in a way that reflected the impact of the protected intersection on pedestrian movements. One exception was the decrease in the rate of crossing outside crosswalks (6.1% to 3.9%) even though the crosswalks became narrower after the protected bike intersection was installed. We hypothesize that a clear delineation between a pedestrian crosswalk and a bike lane may encourage both pedestrians and cyclists to stay in their right-of-way.

As we discuss above in reporting changes in usage of the intersection over the study period, the arrival of e-scooters in Salt Lake City, between 2016 and 2018, led to changes in the way the protected intersection was utilized. We did not report figures for the "other" category prior to the 2018 observation, because the small number of observations contributed to misleading measures. For this reason, we simply compared 2018 observations of e-scooter nonoptimal behavior to 2018 bicyclist behavior. We made this comparison because existing regulations for e-scooter travel typically placed similar restrictions on this mode as were placed on bicycles. We see that e-scooters display higher rates of nonoptimal behavior in every category with the exception of riding in the roadway. E-scooters also demonstrate similar, but slightly higher rates of making exposed left turns and stopping out of place. E-scooter users were much more likely to disobey the signal as compared with their bicycling counterparts, with 16.8% of users crossing against cars' movement. The nonoptimal behavior that e-scooter users were most likely to exhibit was riding on sidewalks. A total of 43.2% of all observed e-scooter users were riding on sidewalks instead of the protected bicycle lane where they were expected to remain. Similarly, e-scooter riders also crossed the intersection within the crosswalk instead of crossing in the bicycle lane at a rate of 22.1% as compared with bicyclists' rate of 5.1%. Generally, e-scooter users were much more likely to exhibit nonoptimal behavior in their approach and interaction with the protected intersection.

4.3. Vehicle Traffic and Safety

Although we did not report changes in drivers' nonoptimal behaviors, there were no collisions or risky signal violations of drivers found during the observation period. Thus, we further examined whether there were differences in traffic volume and the number of collisions since 2016 (post-implementation) (Table 6). The annual traffic data show that there was an increase of 1000 vehicles along the north-south roads at the intersection. This increase was similar to the mean increase in traffic volume of the streets that intersect Salt Lake City, implying there was no significant traffic volume change attributable to the new intersection design. Furthermore, there was no consistent increase in the number of collisions at the intersection during the examined post-implementation period. Four crashes occurred in the 2018 record only, and none of them involved pedestrians or cyclists, or any injury. A possible explanation is that the streets at the intersection became narrower to incorporate the protected intersection design elements (e.g., protected bike lanes, on-street parking, and center islands), possibly resulting in a reduction in traffic speed and no severe injury or fatal crashes. Nevertheless, the increase in the number of crashes is not consistent since 2016 and is not sufficient evidence to prove that the crash events were affected by the new intersection design.

Table 6. Weather, traffic, and collision information by the time when video was recorded.

Video Record	Date	Time of Day	Weather	Outdoor Temperature (°F) *	Precipitation (Inches) *	Annual Average Daily Traffic along the N-S Road †	Number of Annual Collisions †
1	7/31/2015	7 am–7 pm	Clear-dry	62–95	0.00	11,000	0
2	8/19/2016	7 am–7 pm	Clear-dry	69–91	0.00	12,000	0
3	8/24/2018	7 am–7 pm	Clear-dry	66–89	0.05	12,000	4

Source: * Daily data from National Oceanic and Atmospheric Administration (outdoor temperature and precipitation). † Annual data from Utah Department of Transportation. Note: The collisions within the distance of 300 ft (half of the block face) from the intersection center point were counted.

5. Conclusions

This paper highlights examples of changes to usage of a protected intersection in Salt Lake City, UT. We found that after the implementation of a new protected intersection configuration, active transportation usage increased during our three-year study period from 2015 to 2018. Increases in active transportation usage during this time, however, were mostly attributable to a rapid spike in e-scooter users. There has been some speculation among transportation planners and academics whether this new mode might replace trips that would otherwise have been made by walking or bicycling. Initial findings from this limited case study suggest that if e-scooters are, in fact, cannibalizing active transportation trips, the transfer of trips to e-scooters is not significantly diminishing the number of bicycle and pedestrian users at this protected intersection.

We also analyzed the rates of nonoptimal behaviors at the protected intersection, determining how the frequency of these behaviors changed with the implementation of the protected intersection. We found that pedestrian behavior showed a slight change in response to the new configuration, i.e., higher rates of pedestrians were observed staying within the confines of the crosswalk while crossing. More noticeably, bicycle behavior responded to the new infrastructure with reductions in bicyclists crossing within the pedestrian crosswalk, stopping on sidewalks and in the street, and making exposed left turns. The reduction of these nonoptimal behaviors suggests a positive effect on safety for bicycles with the implementation of the protected intersection. Conversely, however, bicyclists tended to cross against the signal at higher rates with the new configuration.

A new user in the protected intersection space was the e-scooter rider. These riders demonstrated higher rates of nonoptimal behaviors than both pedestrians and bicyclists. They were more likely to perform all nonoptimal behaviors than their counterparts on two feet or bicycles except for making exposed left turns. E-scooters utilized the sidewalk at an exceptionally high rate as compared with bicyclists, with 43% of all users preferring this space. While we categorized this as a nonoptimal behavior due to guidance from regulations emerging around the country, this preference should be considered by planners when deciding how to deal with the proliferation of e-scooters. There may be reasons why e-scooter users prefer to ride on the sidewalk as opposed to the bicycle lane. Further research into the reasons for this behavior might elucidate the best ways to plan for and regulate e-scooter use in the future.

Generally, this study showed that active transportation use increased after the implementation of a protected intersection in Salt Lake City, UT. We also showed that many nonoptimal behaviors have been reduced since the new configuration was deployed. This case study gives some evidence that a protected intersection can have positive effects on active transportation volume and safety in a U.S. context. However, we must note that this case study does not assert causality related to the observed changes in volumes and behaviors. Although the before-and-after nature of our samples might be a type of a quasi-experimental design, the small number of samples, i.e., three observation days, limits the internal validity and external validity of our findings. More data and analysis are necessary to begin to make more concrete assertions about the relationships among active transportation volumes, behaviors related to public health and safety, and protected intersection configurations.

Additionally, the context of the intersection is very specific, which limits the ability to generalize beyond the treatment and its surrounding environment. In order to be able to generalize more broadly, future research needs to include more intersections in a wider variety of contexts. We suggest that future research could employ artificial intelligence techniques such as machine learning and computer vision algorithms to facilitate the analysis of greater volumes of data. Such techniques could potentially allow for the study of more intersections and more periods in time to increase the generalizability of research findings. Recent developments in urban transportation, such as the emergence of the COVID-19 pandemic and its effects on travel behavior, have increased the need to incorporate new data into the analysis of active transportation safety. Along with improved methods of observation and analysis, we suggest researchers update this study with more contemporary data.

Author Contributions: Conceptualization, T.L.; methodology, T.L., D.-a.C., and K.P; formal analysis and investigation, T.L, D.-a.C., K.P., and S.H.A; data curation, T.L.; writing—original draft preparation, T.L, D.-a.C., and K.P.; writing—review and editing, T.L, D.-a.C., K.P., and S.H.A.; visualization, D.-a.C.; project administration, T.L. and D.-a.C.; funding acquisition, T.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Salt Lake City and Utah Department of Transportation, grant number 19-8082. This research was also supported by the Utah Agricultural Experiment Station, Utah State University, and approved as journal paper number #9373.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Rojas-Rueda, D.; de Nazelle, A.; Teixidó, O.; Nieuwenhuijsen, M. Health impact assessment of increasing public transport and cycling use in Barcelona: A morbidity and burden of disease approach. *Prev. Med.* **2013**, *57*, 573–579. [CrossRef] [PubMed]
2. Götschi, T.; Garrard, J.; Giles-Corti, B. Cycling as a Part of Daily Life: A Review of Health Perspectives. *Transp. Rev.* **2016**, *36*, 45–71. [CrossRef]
3. Yang, Y.; Wu, X.; Zhou, P.; Gou, Z.; Lu, Y. Towards a cycling-friendly city: An updated review of the associations between built environment and cycling behaviors (2007–2017). *J. Transp. Health* **2019**, *14*, 100613. [CrossRef]
4. Pucher, J.; Buehler, R. Cycling towards a more sustainable transport future. *Transp. Rev.* **2017**, *37*, 689–694. [CrossRef]
5. Pucher, J.; Dill, J.; Handy, S. Infrastructure, programs, and policies to increase bicycling: An international review. *Prev. Med.* **2010**, *50*, S106–S125. [CrossRef] [PubMed]
6. Pucher, J.; Komanoff, C.; Schimek, P. Bicycling renaissance in North America? *Transp. Res. Part A Policy Pract.* **1999**, *33*, 625–654. [CrossRef]
7. Morrison, C.N.; Thompson, J.; Kondo, M.C.; Beck, B. On-road bicycle lane types, roadway characteristics, and risks for bicycle crashes. *Accid. Anal. Prev.* **2019**, *123*, 123–131. [CrossRef] [PubMed]
8. Falbo, N. Protected Intersections For Bicyclists. Available online: http://www.protectedintersection.com/wp-content/uploads/2014/02/Falbo_ProtectedIntersection_Transcript.pdf (accessed on 2 November 2020).
9. Jakobsson, C. Motivational and Volitional Control of Private Automobile Use: The Effectiveness of Transport Policies. *GU/PSYK/AVH*. 2004. Available online: https://gupea.ub.gu.se/bitstream/2077/16128/3/gupea_2077_16128_3.pdf (accessed on 2 November 2020).
10. Low, L. Automobile Restriction Policy in Singapore: The Economic Disincentive Approach. *Wheel Ext.* **1995**, *91*, 12–17.
11. Pucher, J.; Buehler, R. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. *Transp. Rev.* **2008**, *28*, 495–528. [CrossRef]
12. Godefrooij, T. Rediscovering the bicycle: Strategy for a new mobility. In Proceedings of the Velo City '97: Rediscovering the bicycle—Strategies for a new mobility, Barcelona, Spain, 15–19 September 1997; pp. 5–7.
13. Cervero, R.; Caldwell, B.; Cuellar, J. Bike-and-Ride: Build It and They Will Come. *J. Public Transp.* **2013**, *16*, 83–105. [CrossRef]

14. Macmillan, A.; Connor, J.; Witten, K.; Kearns, R.; Rees, D.; Woodward, A. The Societal Costs and Benefits of Commuter Bicycling: Simulating the Effects of Specific Policies Using System Dynamics Modeling. *Environ. Health Perspect.* **2014**, *122*, 335–344. [CrossRef]
15. Marshall, W.E.; Ferenchak, N.N. Why cities with high bicycling rates are safer for all road users. *J. Transp. Health* **2019**, *13*, 100539. [CrossRef]
16. Gotschi, T. Costs and Benefits of Bicycling Investments in Portland, Oregon. *J. Phys. Act. Health* **2011**, *8*, S49–S58. [CrossRef]
17. Murray, C.J.; Lopez, A.D. Mortality by cause for eight regions of the world: Global Burden of Disease Study. *Lancet* **1997**, *349*, 1269–1276. [CrossRef]
18. Webb, C.N. *Motor Vehicle Traffic Crashes as a Leading Cause of Death in the United States, 2015 (Traffic Safety Facts Crash, Stats. Report No. DOT HS 812 499)*; National Highway Traffic Safety Administration: Washington, DC, USA, 2018.
19. Glassbrenner, D. *Safety Belt and Helmet Use in 2002: Overall Results*; National Highway Traffic Safety Administration: Washington, DC, USA, 2002.
20. National Center for Injury Prevention and Control; US Consumer Product Safety Commission (USCPSC). *National Electronic Injury Surveillance System All Injury Program, 2002*; ICPSR Version; ICPSR: Atlanta, GA, USA, 2004.
21. Korve, M.J.; Niemeier, D.A. Benefit-Cost Analysis of Added Bicycle Phase at Existing Signalized Intersection. *J. Transp. Eng.* **2002**, *128*, 40–48. [CrossRef]
22. Wachtel, A.; Lewiston, D. Risk factors for bicycle-motor vehicle collisions at intersections. *ITE J. Inst. Transp. Eng.* **1994**, *64*, 30–35.
23. Wang, Y.; Nihan, N.L. Estimating the risk of collisions between bicycles and motor vehicles at signalized intersections. *Accid. Anal. Prev.* **2004**, *36*, 313–321. [CrossRef]
24. Pérez, K.; Santamariña-Rubio, E. Do advanced stop lines for motorcycles improve road safety? *J. Transp. Health* **2019**, *15*, 100657. [CrossRef]
25. MacLeod, K.E.; Sanders, R.L.; Griffin, A.; Cooper, J.F.; Ragland, D.R. Latent analysis of Complete Streets and traffic safety along an urban corridor. *J. Transp. Health* **2018**, *8*, 15–29. [CrossRef]
26. Chao, P.; Matthias, J.S.; Anderson, M.R. Cyclist Behavior at Signalized Intersections. *Transp. Res. Rec* **1978**, *683*, 34–39.
27. Opiela, K.S.; Khasnabis, S.; Datta, T.K. Determination of the characteristics of bicycle traffic at urban intersections. *Transp. Res. Rec.* **1980**, *743*, 30–38.
28. Carter, D.J.; Hunter, W.W.; Zegeer, C.V.; Stewart, J.R.; Huang, H.F.; Do, A. *Pedestrian and Bicyclist Intersection Safety Indices*; United States Federal Highway Administration: Washington, DC, USA, 2006.
29. Hunter, W.W.; Pein, W.E.; Stutts, J.C. *Bicycle Crash Types: A 1990's Informational Guide*; Federal Highway Administration: Mclean, VA, USA, 1997.
30. Weigand, L. A Review of Literature: Intersection Treatments to Improve Bicycle Access and Safety, Portland: Center for Transportation Studies, Portland State University. 2008. Available online: https://ppms.trec.pdx.edu/media/1223584239DKJJTZE.pdf (accessed on 2 November 2020).
31. Landis, B.W.; Vattikuti, V.R.; Brannick, M.T. Real-Time Human Perceptions: Toward a Bicycle Level of Service. *Transp. Res. Rec. J. Transp. Res. Board* **1997**, *1578*, 119–126. [CrossRef]
32. Jensen, S.U. Pedestrian and Bicyclist Level of Service on Roadway Segments. *Transp. Res. Rec. J. Transp. Res. Board* **2007**, *2031*, 43–51. [CrossRef]
33. Hunter, W.W. Evaluation of Innovative Bike-Box Application in Eugene, Oregon. *Transp. Res. Rec. J. Transp. Res. Board* **2000**, *1705*, 99–106. [CrossRef]
34. Wolfe, M.; Fischer, J.; Deslauriers, C.; Ngai, S.; Bullard, M. Bike Scramble Signal at N Interstate & Oregon, IBPI Research Digest. 2006. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.550.9022&rep=rep1&type=pdf (accessed on 2 November 2020).
35. Jacobsen, P.L. Safety in numbers: More walkers and bicyclists, safer walking and bicycling. *Inj. Prev.* **2015**, *21*, 271–275. [CrossRef]
36. Allen, D.; Bygrave, S.; Harper, H. *Behaviour at Cycle Advanced Stop Lines*; Transport for London: London, UK, 2005; ISBN 1846088372.
37. Wall, G.T.; Davies, D.G.; Crabtree, M. *Capacity Implications of Advanced Stop Lines for Cyclists*; Transport Research Laboratory: London, UK, 2003; ISBN 0968-4107.

38. Hallgren, K.A. Computing inter-rater reliability for observational data: An overview and tutorial. *Tutor. Quant. Methods Psychol.* **2012**, *8*, 23–34. [CrossRef]
39. Koo, T.K.; Li, M.Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef]
40. Shrout, P.E.; Fleiss, J.L. Intraclass correlations: Uses in assessing rater reliability. *Psychol. Bull.* **1979**, *86*, 420–428. [CrossRef]
41. Cicchetti, D. V Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychol. Assess.* **1994**, *6*, 284–290. [CrossRef]
42. Bujang, M.A.; Baharum, N. A simplified guide to determination of sample size requirements for estimating the value of intraclass correlation coefficient: A review. *Arch. Orofac. Sci.* **2017**, *12*, 1–11.

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).