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Did Safe Cycling Infrastructure Still Matter During a COVID-19 Lockdown?

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Received: 16 September 2020; Accepted: 15 October 2020; Published: 19 October 2020

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Abstract: The UK government introduced strict measures (including asking people to work from home and a lockdown) to slow the spread of COVID-19 by limiting people's movement. This led to substantial reductions in traffic, making roads much safer for cyclists. This provides a unique opportunity to study the role played by safe cycling infrastructure. Many UK cities have provided cycling infrastructure to improve safety and encourage cycling. However, access to safe cycling infrastructure varies across neighbourhoods, potentially contributing to inequality. Since roads became safer due to the unprecedented reduction in traffic during the lockdown, safe cycling infrastructure may not play a significant role during this period. On the other hand, safe cycling lanes are often connected to amenities, potentially attracting cyclists even if they confer no additional safety benefit. That is, connectivity might matter more than safety. In this study, we utilised crowdsourced cycling data and regression models to examine the extent to which cycling intensity for non-commuting purposes changes with different types of cycling infrastructure in the city of Glasgow, Scotland, UK. In addition, we selected some areas with large increases in cycling intensity and examined the surrounding environments using Google Street View. Our results showed that non-commuting cycling activities increased significantly after the government interventions on both typical roads and safe cycling lanes while much higher increases were observed on safe cycling lanes than on other roads. A further analysis showed that there were large increases in cycling volumes on both typical roads and safe cycling lanes with good amenities and connectivity, highlighting the importance of these factors when building new cycling infrastructure. Since safe cycling lanes are not equally accessible to people, providing temporary cycling lanes during the pandemic considering these conditions could encourage people to cycle more, and thereby improve their health.

Keywords: COVID-19; cycling; infrastructure; safety

1. Introduction

The world has been facing unprecedented challenges due to the COVID-19 outbreak. In Europe, as of the 30th June 2020, around 1.5 million people had been infected and 0.2 million people had died [1]. The UK recorded a higher number of cases and deaths than any EU country, and introduced strict measures to slow the spread of the virus. One key measure was limiting people's movement. On 16th March, the UK government recommended that people should work from home if possible. One week later, a lockdown was put in place. These strict government interventions had a substantial impact on people's lives. At the start of the lockdown, UK residents were only allowed to go out once per day to buy food, medicine, to deal with emergencies, and to take one form of exercise a day. During this time, there was an 80% reduction in the volume of road transport (including public transport) [2].

One exception was cycling. The number of cycling activities increased around the world, and several countries have emphasized the importance of cycling in their post lockdown transport systems [3]. Cycling has been recognised as a good alternative to private cars due to its convenience and the high prevalence of relatively short daily driving trips. In addition, the health benefits of cycling have been well documented [4,5]. Social distancing and limited opportunities for daily exercise provide good arguments in favour of cycling, especially for exercise. In addition, the substantial reduction in road transport has made roads much safer and more comfortable for cyclists of all abilities.

The lockdown provides a unique opportunity to study the role played by safe cycling infrastructure. One of the main barriers to cycling is the lack of safety [6,7]. Many UK cities have provided cycling infrastructure to improve the level of road safety and thereby encourage cycling. However, the level of accessibility to cycling infrastructure in a city varies across neighbourhoods, potentially contributing to inequality. Since roads became much safer due to the substantial reduction in motorised traffic after the government interventions, safe cycling infrastructure may not play a significant role during this period. On the other hand, safe cycling lanes are often connected to amenities (e.g., rivers, parks etc.), potentially attracting cyclists even if the infrastructure confers no additional safety benefit. If cycling infrastructure remained busy during this period, it may indicate that it is the connectivity of the infrastructure that drives its use rather than the safety benefits.

To answer the above question, we should have robust evidence of where people cycled while the lockdown was in place. Achieving this understanding is important for three reasons. Firstly, it is possible (if not likely) that there will be future disease outbreaks [8]. This means we need to make our cities more resilient to unexpected disease outbreaks and mitigate the impact on people's lives. If we know where people cycled during the lockdown, for example, we can incorporate the evidence to build more sustainable cycling infrastructure in the future. Second, several cities in the UK have provided temporary cycling lanes to encourage people to cycle more, hoping to keep this positive trend and improve people's health. Empirical evidence will help planners provide temporary cycling lanes in appropriate places. Lastly, understanding cycling patterns will be important as societies emerge from the lockdown. The requirement for social distancing has reduced the capacity of public transport, requiring people to find alternatives. It is important that these alternatives are compatible with the need to respond to the climate emergency.

In this study, we utilised crowdsourced cycling data (from the activity-tracking app, Strava) and examined the extent to which cycling intensity for non-commuting purposes increases according to the different types of cycling infrastructure (i.e., typical roads, segregated cycling lanes, shared off road, demarcation, etc.) in the city of Glasgow by using regression models. In addition, we selected some areas with large increases in cycling intensity and examined surrounding environments using Google Street View images and local knowledge.

The rest of this paper is organised as follows. First, we review previous research on the health benefits of cycling and important factors related to cycling behaviour. Second, we explain the data and analytical approach employed in our study in detail. Third, we present empirical results from regression models and detailed examinations of selected cases. Finally, we summarise our results and provide conclusions.

2. Literature Review

A body of research has analysed the impact of cycling on health, and is in agreement about the net health benefits [4,9,10]. Oja et al. [5] conducted a systematic review of 16 published studies on cycling and health, and indicated that 14 of them found cycling to be beneficial in this regard. Mulley et al. [11] focused on the benefits of active travel by including mortality and morbidity changes due to a shift from an inactive to an active lifestyle. Their results showed a weighted benefit of $1.68 per km for walking and $1.12 per km for cycling, respectively. Although cyclists are exposed to air pollution [12] and a risk of traffic collisions [13,14], the health benefits outweigh the negative impacts [15].

Several empirical studies have examined the barriers to cycling [7,16,17], and safety is often mentioned as a main challenge. To improve the safety of cycling, many countries have provided safe cycling infrastructure based on the evidence from empirical studies [18–24]. Several other studies have highlighted the importance of infrastructure in attracting cyclists [25–34]. The type of infrastructure is also important, with cyclists preferring segregated infrastructure [35–37]. In addition, cyclist have been shown to be willing to accept longer journey times if it allows them to use high-quality infrastructure [38]. The above evidence demonstrates improving road safety can promote cycling. However, it is worth noting that access to safe cycling infrastructure varies across neighbourhoods in a city, mainly due to the high cost of installing infrastructure and geographic constraints.

Safety is not the only important factor that cyclists consider. For example, cyclists have been shown to prefer fewer junctions/red lights/stop signs [27,39,40], fewer turns [25,31] and fewer steep inclines [29,31,40]. Other studies indicate a positive effect of proximity to amenities and green spaces on physical activity [41,42]. Positive associations between increased physical activity and factors such as scenery, wooded areas and trails have been documented [43,44]. Cyclists have also been shown to be attracted to areas with mixed land-use [30,45]. In addition, population density, accessibility to jobs and services and proximity to the central business district (CBD) have been shown to encourage cycling [30,46]. These factors are, to some extent, closely associated with the location of safe cycling lanes.

In sum, previous studies have shown the important role of safety in cycling. As explained, road became much safer due to the substantial reductions in motorised traffic after the lockdown was instituted. This may imply that even nonskilled cyclists could use typical roads for exercise, and the relative importance of safe cycling infrastructure may be reduced. However, safe cycling lanes are often connected to amenities, the CBD and other interesting places that influence cycling behaviour. An unequal distribution of safe cycling infrastructure in a city may result in an unequal distribution of health benefits during the lockdown. Therefore, understanding how cyclists use different types of roads during the COVID-19 lockdown will help planners and researchers make our cities more resilient to deal with unexpected future disease outbreaks and make better cycling plans in the future.

3. Data and Analytical Model

3.1. Case Study City

We take the city of Glasgow, Scotland as our case study. The city, the largest in Scotland, has a population of around 630,000. The cycling mode share is relatively low (around 5.6% for travel to work at the 2016 Scottish Household Survey), despite the low level of car ownership compared to other UK cities. In recent years, substantial investments have been made to encourage cycling. Several important corridors had infrastructure installed when the city hosted the Commonwealth Games in 2014. The investment has continued since then. For example, the city is currently rolling out its ambitious Avenues programme, a £114 million investment aimed at reconfiguring the main city centre streets to facilitate walking and cycling and to reduce the volume of motorised traffic. Between 2009 and 2018, cycling volumes in and out of the city centre increased by 111% (https://www.understandingglasgow.com/indicators/transport/cycling).

3.2. Data

For the analyses, we utilised crowdsourced cycling data collected from the activity-tracking app Strava from July 2019 to March 2020. Strava Metro provides processed cycling counts for each road link on OpenStreetMap. The data also include whether each trip is classed as commuting or non-commuting. Several previous studies, including studies in Glasgow, examined the validity of Strava data for cycling research, and most showed positive results (e.g., high correlations) [47,48]. However, they used an earlier version of the Strava Metro product that includes raw cycling counts at the link level. From 2018, Strava Metro has provided binned count data by aggregating cycling counts in five-count buckets to protect privacy. That is, cycling counts are rounded up to the nearest multiple of five. Counts of three or fewer cyclists become zero. Considering the relatively low mode share of cyclists in most UK cities and that only a small proportion of cyclists use the Strava app, a new validation analysis is required. To do this, we collected cycling counts from five automatic counters in and around the city centre and compared them with the binned counts taken from Strava for the same locations (daily total counts were used). These are presented in Figure 1.

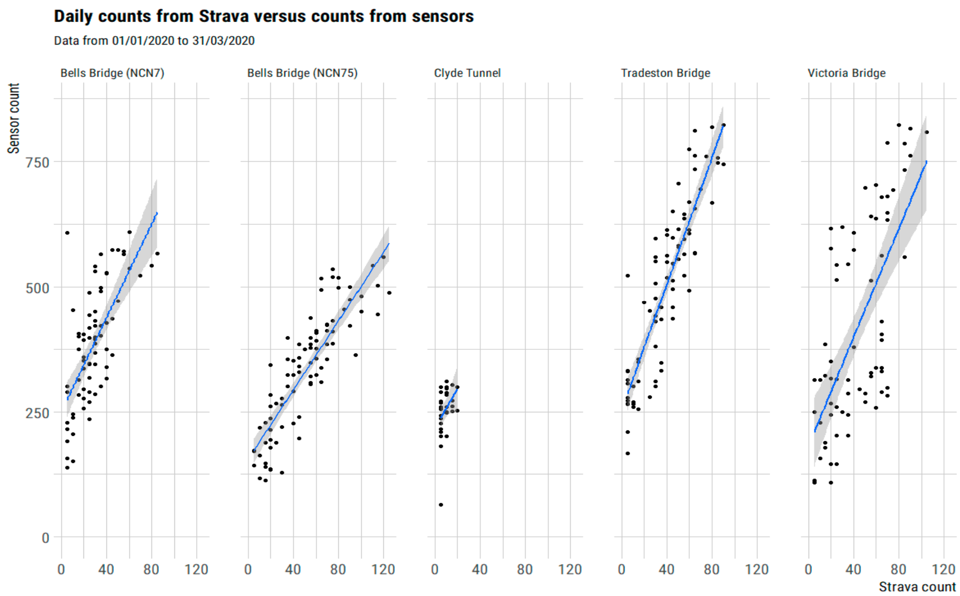

Figure 1. Comparison of counts from sensors and from Strava Metro.

Figure 1 shows that there is an approximately linear relationship between the two sources of counts. The scales on the axes are very different, with only around 10% of the cycling trips being registered in Strava Metro. Despite this, the counts from Strava Metro correspond reasonably well with the counts taken from the automatic counters. Although this is promising, extra caution is advised because these are only a small number of busy places.

Figure 2 shows the 7-day moving average of total cycling distances (calculated as the average of the past 7 days of the sum of total cycling counts * length of links (km)) for commuting and non-commuting trips made by Strava users. We can see the seasonality effect (i.e., high level of cycling activities in Summer 2019) and high commuting cycling volumes before government interventions.

Figure 3 shows the same data but only from January 2020 to March 2020. When people were asked to work from home, the volume of commuting cycling trips started to reduce significantly. During the lockdown, few commuting cycling trips were observed. On the other hand, the volume of non-commuting trips began to increase significantly. This may be people cycling more for daily exercise.

For the main analyses, we calculated a measure of daily non-commuting cycling intensity for 8 different types of cycling infrastructure: Nothing on road, Calmed/Low Traffic on road, Demarcation on road, Leisure off road, Park Route off road, Segregated on road, Shared off road and Signed on road. Specifically, we divided total non-commuting cycling distance (i.e., sum of total non-commuting cycling counts multiplied by the length of links within a particular infrastructure type—we assumed that all cyclists who used a link travel the full distance) for a day with the total network distance of that cycling infrastructure type. The unit resulting from this should be interpreted as follows: for each kilometre of a given infrastructure type, it shows the number of kilometres cycled on it. We adopted this approach because typical roads (i.e., Nothing on road) account for about 94% of the total roads while safe cycling lanes (i.e., Park route, Segregated lanes and Shared off road) cover only around 4.2% of the total network.

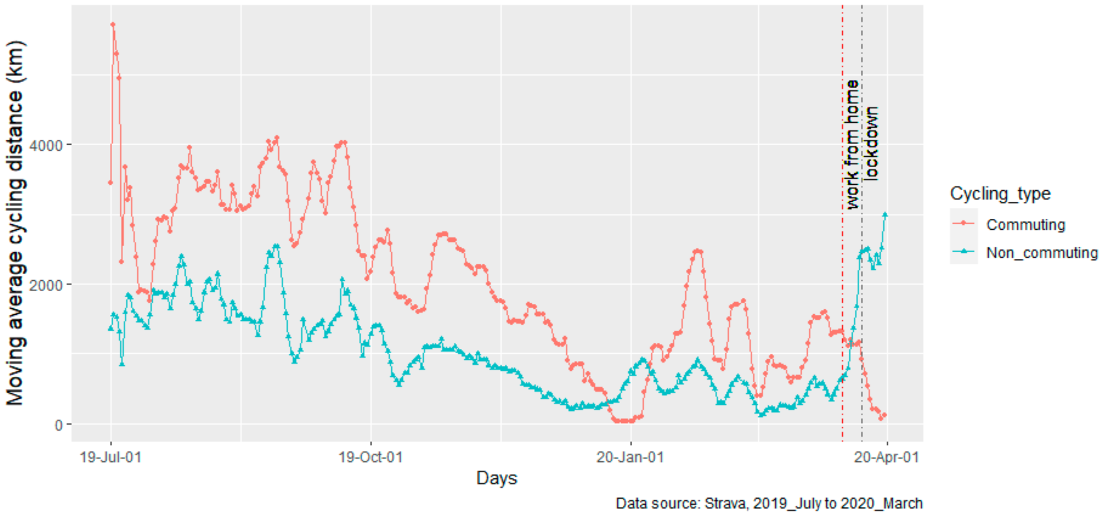

Figure 2. 7-day moving average of commuting and non-commuting cycling distances (km): July 2019–March 2020.

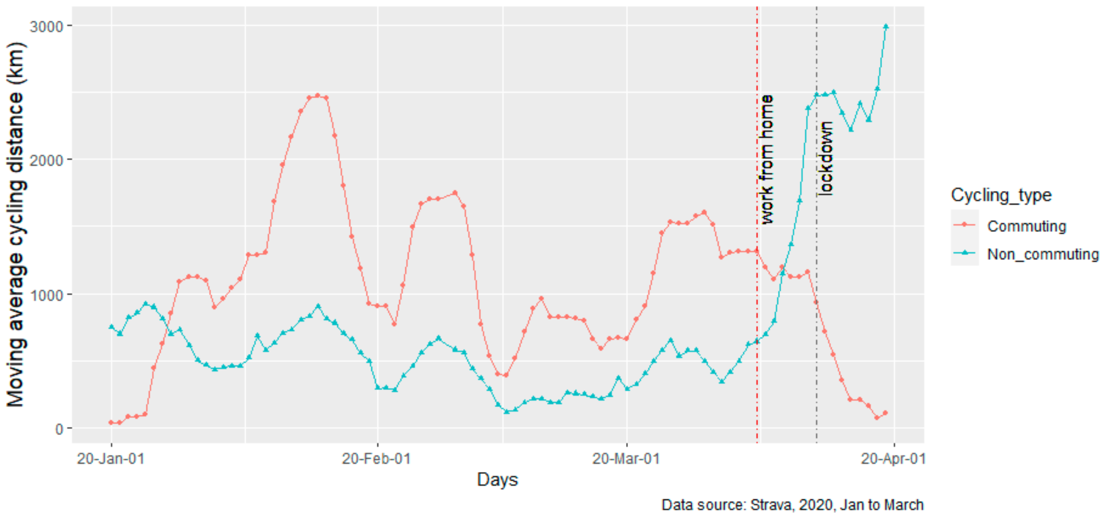

Figure 3. 7-day moving average of commuting and non-commuting cycling distances (km): January 2020–March 2020.

We focused on non-commuting cycling trips for the main analyses because most workers were prohibited from attending their workplace during this period. Figure 4 shows the study area (the city of Glasgow) with the distribution of different types of cycling infrastructure. As we can see, there are fewer safe cycling lanes (e.g., Shared off road, Segregated lanes) in neighbourhoods located in the east part of Glasgow (mostly poor neighbourhoods), and safe cycling lanes are well connected with attractive public spaces such as rivers and parks.

Figures 5 and 6 show the 7-day moving average of cycling intensity for commuting and non-commuting trips, respectively, according to the different types of cycling infrastructure. Figure 5 shows that commuting cycling intensity decreased for most roads after the implementation of government interventions, especially lockdown. Interestingly, there was still high commuting cycling intensity for Shared off road before the lockdown. There was a significant increase in the non-commuting cycling intensity for Shared off road between the request that people work from home and the implementation of the lockdown. During the lockdown, we can still see high non-commuting cycling intensity for Shared off road. This implies that people used safe cycling lanes more compared to typical roads (Nothing on roads) for exercise after government interventions, even though typical roads became much safer due to the reduction in traffic. Figure 6 also shows that non-commuting cycling intensity increased for most roads, even for typical roads.

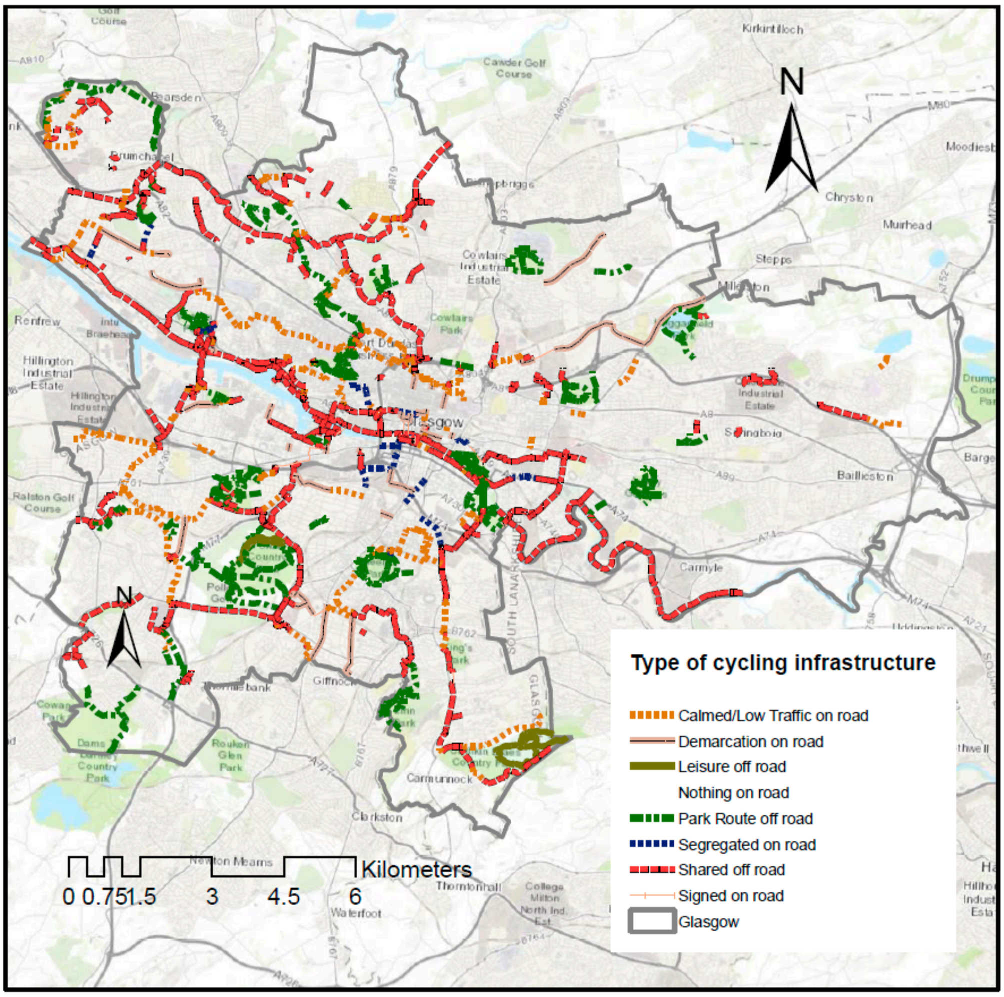

Figure 4. Study area with cycling infrastructure in the city of Glasgow.

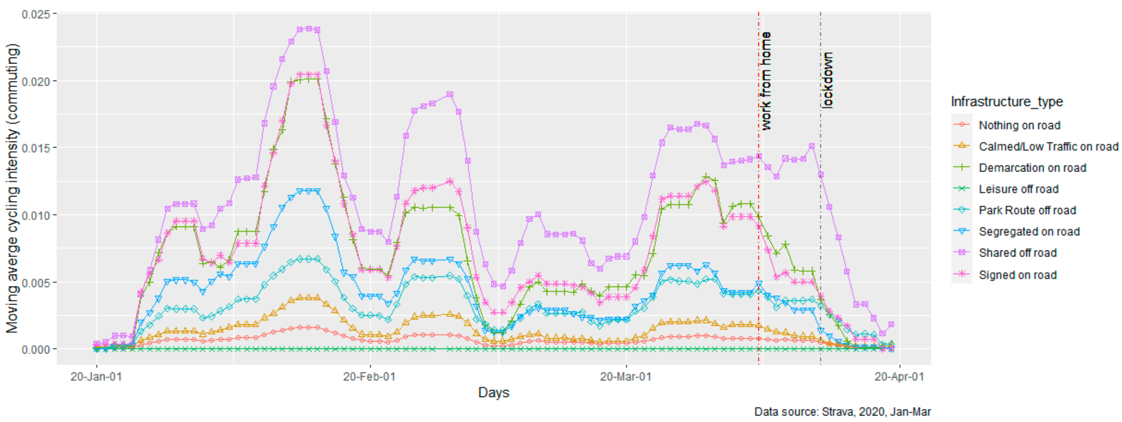

Figure 5. 7-day moving average cycling intensity for commuting trips across infrastructure types.

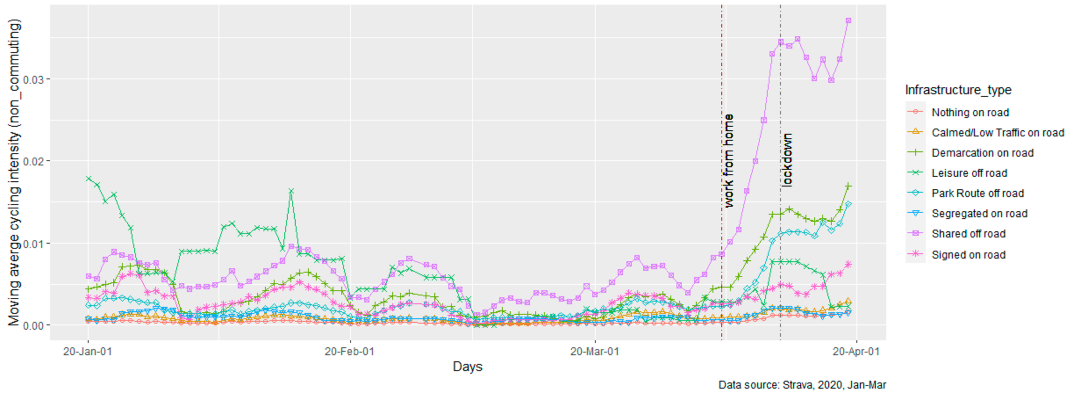

Figure 6. 7-day moving average cycling intensity for non-commuting trips across infrastructure types.

Because cycling is sensitive to weather conditions such as rain and temperature [49–51], we obtained weather information for the Glasgow area from the NOAA Integrated Surface Database. The worldmet package in R provides easy access to the data for most cities in the world [52]. Specifically, we calculated maximum temperature, total precipitation and mean wind speed. In addition, we measured the daylight hours (length of day) using the suncalc R-package [53]. We believe these variables can control for seasonality effects in cycling volumes. After removing all missing values, we have a total of 1968 observations (246 days * 8 types of cycling infrastructure).

3.3. Analytical Method

In this study, we examined the effects of government interventions (i.e., *Work from home* and *Lockdown*) on cycling intensity for the 8 types of cycling infrastructure. That means, we had 8 regression models. Although we have time series data, the Durbin-Watson test shows that there is no serious serial correlation in the residuals from our regression models. Therefore, we used simple linear regression models for our analyses. To check the robustness of our results, we also employed regression models with ARMA errors (using the auto.arima function from the forecast R-package [54]), and results are shown in the Appendix A. We confirm that results are consistent. The model can be written as follows:

$$\sqrt{y_t} \sim N\Big(\alpha + \beta^{\top}_{interventions} x_{interventions\_t} + \beta_{dayofweek} x_{dayofweek\_t} + \beta^{\top}_{weather} x_{weather\_t}\ ,\ \sigma^2\Big),\ t = 1, \ldots, 246. \quad (1)$$

where y_t is the non-commuting cycling intensity (i.e., sum of total non-commuting cycling counts multiplied by the length of links within a particular infrastructure type divided by the total network distance of that cycling infrastructure type) on day t, and $x_{interventions\_t}$, $x_{dayofweek\_t}$ and $x_{weather\_t}$ represent government interventions, the day of the week and weather conditions (i.e., max temperature, level of precipitation, average wind speed and daylight hours), respectively. We took the square root of y_t due to its skewed distribution with some zero values.

In addition, we selected 6 roads with a high number of cycling activities and used Google Street View images combined with local knowledge to examine the potential influences of surrounding environments on non-commuting cycling intensity.

4. Results

Table 1 shows the results from 8 linear regression models. In general, the trends are consistent with previous studies. Cycling intensity is higher on Sundays compared to other days of the week. This is because we focused on non-commuting cycling trips. As expected, cycling intensity is sensitive to weather conditions regardless of cycling infrastructure types. Max temperature has positive associations, while the level of precipitation is negatively related to cycling intensity. Interestingly, daylight hours have positive relationships with cycling intensity only on safe cycling lanes (i.e., Park, Segregated and Shared off roads).

Our models show that the two government interventions (i.e., *Work from home* and *Lockdown*) have positive impacts on non-commuting cycling intensity for most types of cycling infrastructure. This result indicates that cycling became a popular way of exercising during the pandemic. Especially, cycling intensity on typical roads (Nothing on road) also increased significantly after government interventions were in place. This implies that the improvement of safety due to the substantial reduction in the volume of motorised traffic may have encouraged people to cycle more on typical roads.

However, some types of cycling infrastructure do not show any significant changes. Specifically, there was no significant increase in cycling intensity on segregated lanes after government interventions. This could be due to the location of segregated lanes. As seen in Figure 4, most segregated lanes were built around city centre areas where most jobs are located. During the lockdown, only essential workers were allowed to work outside of their homes, potentially reducing the use of these safe cycling lanes.

The estimates of *Work from home* and *Lockdown* from the models indicate that there were relatively higher increases in cycling intensity on Demarcation on road, Park Route off road and Shared off road compared to typical roads. This shows that safe cycling infrastructure still matters during the lockdown, and the unequal distribution of the cycling infrastructure could result in unequal health benefits across areas in a city. To further examine the potential effects of surrounding environments on cycling intensity, we calculated the changes in average cycling distance per link after government interventions. Specifically, we calculated average cycling distances per link between March 1st and 15th (Pre-period), 16th and 22nd (Work from home) and 23rd and 31st (Lockdown). Then, we calculated differences after Work from home and Lockdown compared to the Pre-period. Figure 7 shows the changes in average cycling distance per link after Work from home and Lockdown, respectively. We can see large increases in cycling intensity in both periods alongside the rivers and parks. This implies the importance of amenities on the route choice of cyclists for leisure or exercise. In addition, most of these routes are shared off road. However, we can also see some large increases on typical roads. These roads are mostly main roads in Glasgow that connect to attractive places such as parks, shops and supermarkets.

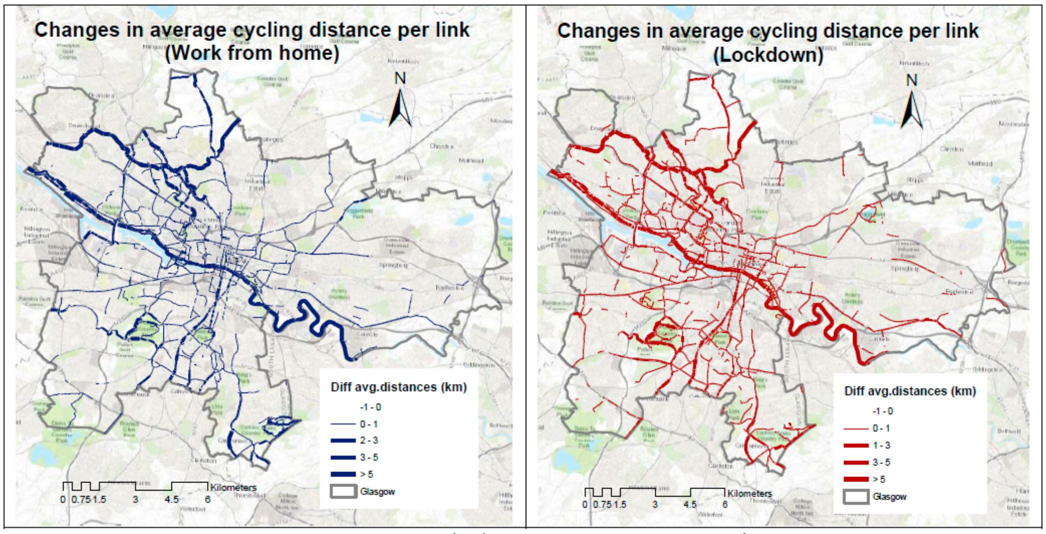

Figure 7. Changes in average cycling distance per link (km) comparing Work from home/Lockdown and Pre-period average cycling distances.

Table 1. Effects of government interventions on cycling intensity across different types of cycling infrastructure.

	Nothing	Calmed/Low	Demarcation	Leisure	Park	Segregated	Shared off	Signed
	Estimate	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**
Constant	0.022 ***	0.019 ***	0.076 ***	0.097 ***	0.031 ***	0.01	0.065 ***	0.040 ***
Government interventions								
Work from home	0.012 ***	0.012 ***	0.051 ***	0.03	0.043 ***	0.01	0.078 ***	0.01
Lockdown	0.014 ***	0.010 **	0.051 ***	−0.01	0.052 ***	−0.01	0.071 ***	0.01
Day of week (ref:Sunday)								
Monday	−0.012 ***	0.00	−0.037 ***	−0.081 ***	−0.019 ***	0.01	−0.033 ***	−0.015 **
Tuesday	−0.008 ***	0.006 **	−0.034 ***	−0.074 ***	−0.01	0.010 **	−0.019 ***	−0.01
Wednesday	−0.011 ***	0.00	−0.036 ***	−0.066 ***	−0.015 ***	0.01	−0.033 ***	−0.013 *
Thursday	−0.009 ***	0.00	−0.031 ***	−0.062 ***	−0.009 **	0.016 ***	−0.025 ***	−0.014 *
Friday	−0.012 ***	0.00	−0.043 ***	−0.075 ***	−0.01	0.00	−0.017 **	−0.023 ***
Saturday	−0.005 ***	0.00	−0.019 ***	−0.02	0.00	0.00	0.01	−0.026 ***
Weather conditions								
Max temperature	0.001 ***	0.001 ***	0.004 ***	0.004 ***	0.002 ***	0.002 ***	0.004 ***	0.003 ***
Precipitation	−0.001 ***	−0.001 ***	−0.002 ***	−0.001 ***	−0.001 ***	−0.001 ***	−0.002 ***	−0.001 ***
Mean wind	−0.001 ***	−0.001 **	−0.002 **	0.00	−0.002 **	0.00	−0.004 ***	−0.002 *
Daylight hours	0.00	0.00	0.00	0.00	0.002 **	0.001 *	0.003 ***	0.00
Sample size	246	246	246	246	246	246	246	246
Goodness-of-fit								
R^2	0.72	0.45	0.64	0.34	0.65	0.50	0.72	0.40
Adjusted R^2	0.71	0.43	0.62	0.30	0.64	0.47	0.71	0.37

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. See Appendix A for results from regression models with ARMA errors.

We selected 6 places (see Figure 8) that have substantial increases in average cycling distance after the lockdown for further discussion. Picture 1, 2 and 3 show typical roads (Nothing on roads). They are one of the busiest roads that connect to local attractions such as shops, supermarkets, parks, museums, etc. During the lockdown, the traffic volumes reduced significantly on these roads, making them safer and more attractive to cyclists. This implies that cyclists do use these roads more frequently for exercise or to buy food. It also implies that there are small or no increases in average cycling distance on most typical small local roads.

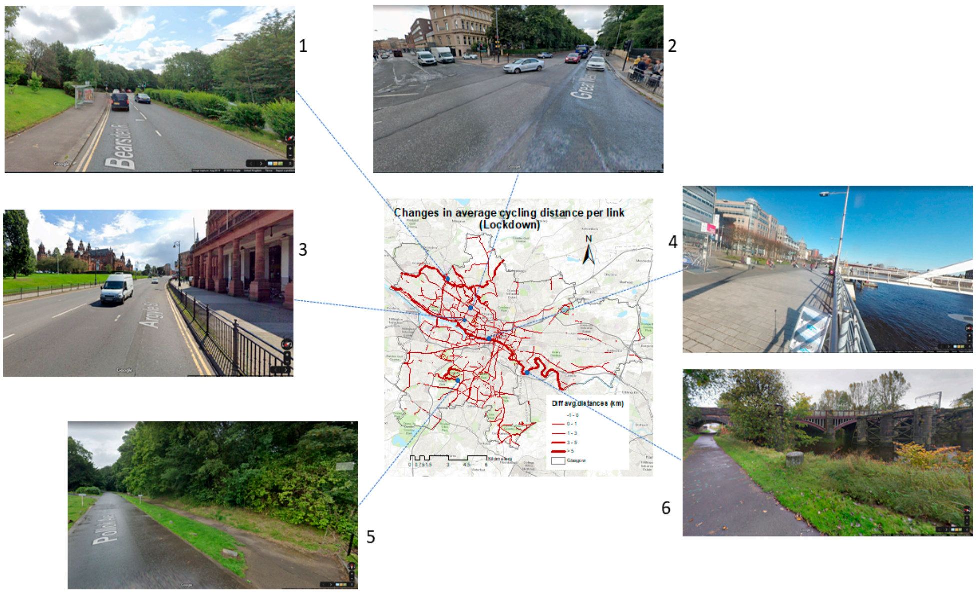

Figure 8. Six selected places with high increases in average cycling distance after the lockdown (Google Street View images).

Picture 4 and 6 are Shared off road next to the River Clyde. These areas had relatively high cycling volumes even before the pandemic due to attractive scenery and their connections to the city centre. Picture 5 is Park off road. Public parks were open to the public for exercise during the pandemic.

5. Conclusions

The pandemic has had significant negative impacts on our society. Due to its contagious characteristics and no available vaccine, many countries have implemented strict policies to limit people's movement. The UK government made two interventions in March to limit mobility, leading to substantial reductions in motorised traffic. This made typical roads much safer and more attractive for cyclists. With limited opportunities for daily exercise during the lockdown, many cities noticed substantial increases in cycling, potentially improving public health. However, it is not clear whether cyclists used typical roads that became safer or continued to use safe cycling lanes. If cyclists still preferred safe cycling lanes during the lockdown, it could lead to unequal health effects for residents since safe cycling lanes are not equally accessible across neighbourhoods in a city. In this paper, we investigated the effects of two UK government interventions (*Work from home* and *Lockdown*) on non-commuting cycling activities, and how they vary according to the different types of cycling infrastructure in the city of Glasgow, Scotland.

We found that non-commuting cycling activities increased significantly after the government interventions. As expected, cyclists used typical roads more frequently after government interventions. Typical roads became substantially less busy, making them more attractive to even nonskilled cyclists. Safety is one of the key barriers for non-cyclists becoming cyclists. This is often used to justify the importance of providing good cycling infrastructure. Our result implies that safety should be the policy target.

However, we also found different effects of government interventions on non-commuting cycling intensity across the 8 types of cycling infrastructure. Specifically, there were much higher increases in cycling intensity on safe cycling lanes such as Shared off road and Park off road that have good amenities and are well connected to local attractions compared to other types of cycling infrastructure. There was no significant increase in non-commuting cycling intensity on segregated lanes. This could be due to their locations.

Further analysis showed that there were higher increases in non-commuting cycling activities on roads that have good amenities such as rivers, parks or are connected to important places such as supermarkets, even for typical roads. This implies that amenities and connections to attractions should be considered when building new cycling infrastructure in the future. Since safe cycling lanes are not equally accessible for people from different neighbourhoods, providing temporary cycling lanes during the pandemic considering these conditions could encourage people to cycle more, improving their health.

There are limitations to our study. First, Strava users are not representative of general cyclists. They tend to be young, male and experienced cyclists. In addition, binned Strava data could result in information loss. This implies that extra caution must be exercised when interpreting our results. However, it is worth nothing that experienced cyclists are less sensitive to safety issues. Therefore, our conclusion will likely be consistent. We also compared the counts from Strava to a ground-truth measure which showed a high correlation. Second, we examined the short-term effects of the pandemic by using 2 weeks of cycling data during the lockdown. Cycling behaviour may change as cyclists get used to the changes caused by the pandemic. Studying a longer time period will help understand more comprehensive effects of the pandemic on cycling patterns across different types of cycling infrastructure.

Author Contributions: Conceptualization, J.H.; methodology: J.H. and D.M.; formal analysis, J.H., D.M. and V.R.; writing—original draft preparation, J.H.; writing—review and editing, D.M. and V.R. All authors have read and agreed to the published version of the manuscript.

Funding: Economic and Social Research Council (Grant ES/S007105/1).

Acknowledgments: The authors would like to acknowledge support from the Economic and Social Research Council-funded Urban Big Data Centre at the University of Glasgow (Grant ES/L011921/1, ES/S007105/1) as well as thank the Neighbourhoods and Sustainability team at Glasgow City Council for sharing data.

Conflicts of Interest: There are no conflicts of interest.

Appendix A Appendix

Table A1. Results from the regression models with ARMA errors.

	Nothing	Calmed/Low	Demarcation	Leisure (1,0,1)	Park (0,0,3)	Segregate	Shared off	Signed (1,0,1)
	Estimate	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**	**Estimate**
Constant	0.022 ***	0.019 ***	0.077 ***	0.098 ***	0.033 ***		0.065 ***	
Government interventions								
Work from home	0.012 ***	0.012 ***	0.051 ***	0.028	0.043 ***	0.006	0.079 ***	0.008
Lockdown	0.014 ***	0.010 **	0.051 ***	−0.009	0.047 ***	−0.011 *	0.071 ***	0.006
Day of week (ref:Sunday)								
Monday	−0.012 ***	0.000	−0.037 ***	−0.082 ***	−0.020 ***	0.007 *	−0.033 ***	−0.015 **
Tuesday	−0.008 ***	0.006 **	−0.034 ***	−0.074 ***	−0.005	0.011 ***	−0.019 ***	−0.004
Wednesday	−0.012 ***	−0.001	−0.036 ***	−0.067 ***	−0.015 ***	0.007 *	−0.033 ***	−0.012 *
Thursday	−0.009 ***	0.003	−0.031 ***	−0.062 ***	−0.008 **	0.018 ***	−0.025 ***	−0.013 *
Friday	−0.012 ***	0.004	−0.043 ***	−0.075 ***	−0.004	0.005	−0.017 ***	−0.021 ***
Saturday	−0.005 ***	−0.002	−0.019 ***	−0.020 *	0.001	−0.002	0.005	−0.024 ***
Weather conditions								
Max temperature	0.001 ***	0.001 ***	0.004 ***	0.003 **	0.002 ***	0.002 ***	0.004 ***	0.002 ***
Precipitation	−0.001 ***	−0.001 ***	−0.002 ***	−0.001 ***	−0.001 ***	−0.001 ***	−0.002 ***	−0.001 ***
Mean wind	−0.001 ***	−0.001 **	−0.002 **	−0.001	−0.002 ***	−0.001	−0.004 ***	−0.002
Daylight hours	0.000	0.001	−0.001	−0.003	0.002 **	0.002 ***	0.003 ***	0.004 ***
ar1				0.708				0.984 ***
ma1				−0.663	0.031			−0.906 ***
ma2					0.213 ***			
ma3					0.223 ***			
Sigma	0	0	0.001	0.002	0	0	0.001	0.001
Likelihoood	923.95	757.86	581.05	397.63	646.51	665	537.84	519.53

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

References

1. European Centre for Disease Prevention and Control COVID-19 Situation Update for the EU/EEA and the UK, as of 19 June 2020. Available online: https://www.ecdc.europa.eu/en/cases-2019-ncov-eueea (accessed on 19 June 2020).
2. HM Government, Our Plan to Rebuild: The UK Government's COVID-19 Recovery Strategy. 2020. Available online: https://www.gov.uk/government/publications/our-plan-to-rebuild-the-uk-governments-covid-19-recovery-strategy (accessed on 19 July 2020).
3. Sandor, A. Cycling is Booming during Coronavirus—Let's Keep it that Way. *The Independent*. 2020. Available online: https://www.independent.co.uk/voices/coronavirus-uk-cycling-new-york-wuhan-pollution-driving-a9484976.html (accessed on 22 July 2020).
4. Johan de Hartog, J.; Boogaard, H.; Nijland, H.; Hoek, G. Do the health benefits of cycling outweigh the risks? *Environ. Health Perspect* **2010**, *118*, 1109–1116. [CrossRef]
5. Oja, P.; Titze, S.; Bauman, A.; de Geus, B.; Krenn, P.; Reger-Nash, B.; Kohlberger, T. Health benefits of cycling: A systematic review. *Scand. J. Med. Sci. Sports* **2011**, *21*, 496–509. [CrossRef] [PubMed]
6. Swiers, R.; Pritchard, C.; Gee, I. A cross sectional survey of attitudes, behaviours, barriers and motivators to cycling in University students. *J. Transp. Health* **2017**, *6*, 379–385. [CrossRef]
7. Manaugh, K.; Boisjoly, G.; El-Geneidy, A. Overcoming barriers to cycling: Understanding frequency of cycling in a University setting and the factors preventing commuters from cycling on a regular basis. *Transportation* **2017**, *44*, 871–884. [CrossRef]
8. Garrington, D. Halt Destruction of Nature or Suffer Even Worse Pandemics, Say World's Top Scientists. *The Guardian*. Available online: https://www.theguardian.com/world/2020/apr/27/halt-destruction-nature-worse-pandemics-top-scientists (accessed on 27 April 2020).
9. Celis-Morales, C.A.; Lyall, D.M.; Welsh, P.; Anderson, J.; Steell, L.; Guo, Y.; Maldonado, R.; Mackay, D.F.; Pell, J.P.; Sattar, N.; et al. Association between active commuting and incident cardiovascular disease, cancer, and mortality: Prospective cohort study. *BMJ* **2017**, *357*, j1456. [CrossRef] [PubMed]
10. Gao, J.; Helbich, M.; Dijst, M.; Kamphuis, C.B.M. Socioeconomic and demographic differences in walking and cycling in the Netherlands: How do these translate into differences in health benefits? *J. Transp. Health* **2017**, *6*, 358–365. [CrossRef]
11. Mulley, C.; Tyson, R.; McCue, P.; Rissel, C.; Munro, C. Valuing active travel: Including the health benefits of sustainable transport in transportation appraisal frameworks. *Res. Transp. Bus. Manag.* **2013**, *7*, 27–34. [CrossRef]
12. Lee, K.; Sener, I.N. Understanding Potential Exposure of Bicyclists on Roadways to Traffic-Related Air Pollution: Findings from El Paso, Texas, Using Strava Metro Data. *Int J. Environ. Res. Public Health* **2019**, *16*, 371. [CrossRef]
13. Schepers, J.P.; Heinen, E. How does a modal shift from short car trips to cycling affect road safety? *Accid. Anal. Prev.* **2013**, *50*, 1118–1127. [CrossRef]
14. Welsh, C.; Celis-Morales, C.A.; Ho, F.; Lyall, D.M.; Mackay, D.; Ferguson, L.; Sattar, N.; Gray, S.R.; Gill, J.M.R.; Pell, J.P.; et al. Association of injury related hospital admissions with commuting by bicycle in the UK: Prospective population based study. *BMJ* **2020**, *368*, m336. [CrossRef]
15. Tainio, M.; de Nazelle, A.J.; Götschi, T.; Kahlmeier, S.; Rojas-Rueda, D.; Nieuwenhuijsen, M.J.; de Sá, T.H.; Kelly, P.; Woodcock, J. Can air pollution negate the health benefits of cycling and walking? *Prev. Med.* **2016**, *87*, 233–236. [CrossRef]
16. Christie, N.; Kimberlee, R.; Towner, E.; Rodgers, S.; Ward, H.; Sleney, J.; Lyons, R. Children aged 9–14 living in disadvantaged areas in England: Opportunities and barriers for cycling. *J. Transp. Geogr.* **2011**, *19*, 943–949. [CrossRef]
17. Salmon, J.; Salmon, L.; Crawford, D.A.; Hume, C.; Timperio, A. Associations among Individual, Social, and Environmental Barriers and Children's Walking or Cycling to School. *Am. J. Health Promot.* **2007**, *22*, 107–113. [CrossRef] [PubMed]
18. Hull, A.; O'Holleran, C. Bicycle infrastructure: Can good design encourage cycling? *Urban. Plan. Transp. Res.* **2014**, *2*, 369–406. [CrossRef]
19. Lawson, A.R.; Pakrashi, V.; Ghosh, B.; Szeto, W.Y. Perception of safety of cyclists in Dublin City. *Accid. Anal. Prev.* **2013**, *50*, 499–511. [CrossRef] [PubMed]

20. Leden, L.; Gårder, P.; Pulkkinen, U. An expert judgment model applied to estimating the safety effect of a bicycle facility. *Accid. Anal. Prev.* **2000**, *32*, 589–599. [CrossRef]
21. Thomas, B.; DeRobertis, M. The safety of urban cycle tracks: A review of the literature. *Accid. Anal. Prev.* **2013**, *52*, 219–227. [CrossRef] [PubMed]
22. Winters, M.; Brauer, M.; Setton, E.M.; Teschke, K. Built Environment Influences on Healthy Transportation Choices: Bicycling versus Driving. *J. Urban. Health* **2010**, *87*, 969–993. [CrossRef]
23. Goodman, A.; Panter, J.; Sharp, S.J.; Ogilvie, D. Effectiveness and equity impacts of town-wide cycling initiatives in England: A longitudinal, controlled natural experimental study. *Soc. Sci. Med.* **2013**, *97*, 228–237. [CrossRef]
24. Norwood, P.; Eberth, B.; Farrar, S.; Anable, J.; Ludbrook, A. Active travel intervention and physical activity behaviour: An evaluation. *Soc. Sci. Med.* **2014**, *113*, 50–58. [CrossRef]
25. Broach, J.; Dill, J.; Gliebe, J. Where do cyclists ride? A route choice model developed with revealed preference GPS data. *Transp. Res. Part A Policy Pract.* **2012**, *46*, 1730–1740. [CrossRef]
26. Caulfield, B. Re-cycling a city—Examining the growth of cycling in Dublin. *Transp. Res. Policy Pract.* **2014**, *61*, 216–226. [CrossRef]
27. Caulfield, B.; Brick, E.; McCarthy, O.T. Determining bicycle infrastructure preferences—A case study of Dublin. *Transp. Res. Part D Transp. Environ.* **2012**, *17*, 413–417. [CrossRef]
28. Dill, J.; Gliebe, J. Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route Choice. In *Understanding and Measuring Bicycling Behavior: A Focus on Travel Time and Route Choice*; Portland State University Library: Portland, OR, USA, 2008.
29. Fraser, S.D.S.; Lock, K. Cycling for transport and public health: A systematic review of the effect of the environment on cycling. *Eur. J. Public Health* **2010**, *21*, 738–743. [CrossRef]
30. Hankey, S.; Lindsey, G.; Wang, X.; Borah, J.; Hoff, K.; Utecht, B.; Xu, Z. Estimating use of non-motorized infrastructure: Models of bicycle and pedestrian traffic in Minneapolis, MN. *Landsc. Urban Plan.* **2012**, *107*, 307–316. [CrossRef]
31. Hood, J.; Sall, E.; Charlton, B. A GPS-based bicycle route choice model for San Francisco, California. *Transp. Lett.* **2011**, *3*, 63–75. [CrossRef]
32. Winters, M.; Davidson, G.; Kao, D.; Teschke, K. Motivators and deterrents of bicycling: Comparing influences on decisions to ride. *Transportation* **2010**, *38*, 153–168. [CrossRef]
33. Winters, M.; Teschke, K. Route Preferences among Adults in the near Market for Bicycling: Findings of the Cycling in Cities Study. *Am. J. Health Promot.* **2010**, *25*, 40–47. [CrossRef]
34. Hong, J.; McArthur, D.P.; Livingston, M. The evaluation of large cycling infrastructure investments in Glasgow using crowdsourced cycle data. *Transportation* **2019**, 1–14. [CrossRef]
35. Garrard, J.; Rose, G.; Lo, S.K. Promoting transportation cycling for women: The role of bicycle infrastructure. *Prev. Med.* **2008**, *46*, 55–59. [CrossRef] [PubMed]
36. Gatersleben, B.; Appleton, K.M. Contemplating cycling to work: Attitudes and perceptions in different stages of change. *Transp. Res. Part A Policy Pract.* **2007**, *41*, 302–312. [CrossRef]
37. Wardman, M.; Tight, M.; Page, M. Factors influencing the propensity to cycle to work. *Transp. Res. Part A Policy Pract.* **2007**, *41*, 339–350. [CrossRef]
38. Tilahun, N.Y.; Levinson, D.M.; Krizek, K.J. Trails, lanes, or traffic: Valuing bicycle facilities with an adaptive stated preference survey. *Transp. Res. Part A Policy Pract.* **2007**, *41*, 287–301. [CrossRef]
39. Sener, I.N.; Eluru, N.; Bhat, C.R. An analysis of bicycle route choice preferences in Texas, US. *Transportation* **2009**, *36*, 511–539. [CrossRef]
40. Menghini, G.; Carrasco, N.; Schussler, N.; Axhausen, K. Route choice of cyclists in Zurich. *Transp. Res. Part A Policy Pract.* **2010**, *44*, 754–765. [CrossRef]
41. Kaczynski, A.T.; Henderson, K.A. Environmental Correlates of Physical Activity: A Review of Evidence about Parks and Recreation. *Leis. Sci.* **2007**, *29*, 315–354. [CrossRef]
42. Moudon, A.V.; Lee, C.; Cheadle, A.D.; Collier, C.W.; Johnson, D.; Schmid, T.L.; Weather, R.D. Cycling and the built environment, a US perspective. *Transp. Res. Part D Transp. Environ.* **2005**, *10*, 245–261. [CrossRef]
43. Brownson, R.C.; Baker, E.A.; Housemann, R.A.; Brennan, L.K.; Bacak, S.J. Environmental and Policy Determinants of Physical Activity in the United States. *Am. J. Public Health* **2001**, *91*, 1995–2003. [CrossRef]
44. Kaczynski, A.T.; Potwarka, L.R.; Saelens, B.E. Association of Park Size, Distance, and Features with Physical Activity in Neighborhood Parks. *Am. J. Public Health* **2008**, *98*, 1451–1456. [CrossRef]

45. Zhao, P.; Li, S. Bicycle-metro integration in a growing city: The determinants of cycling as a transfer mode in metro station areas in Beijing. *Transp. Res. Part A Policy Pract.* **2017**, *99*, 46–60. [CrossRef]
46. Saelens, B.E.; Sallis, J.F.; Frank, L.D. Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Ann. Behav. Med.* **2016**, *25*, 80–91. [CrossRef] [PubMed]
47. Jestico, B.; Nelson, T.; Winters, M. Mapping ridership using crowdsourced cycling data. *J. Transp. Geogr.* **2016**, *52*, 90–97. [CrossRef]
48. Livingston, M.; McArthur, D.; Hong, J.; English, K. Predicting cycling volumes using crowdsourced activity data. *Environ. Plan B Urban Anal. City Sci.* **2020**. [CrossRef]
49. El-Assi, W.; Salah Mahmoud, M.; Nurul Habib, K. Effects of built environment and weather on bike sharing demand: A station level analysis of commercial bike sharing in Toronto. *Transportation* **2017**, *44*, 589–613. [CrossRef]
50. An, R.; Zahnow, R.; Pojani, D.; Corcoran, J. Weather and cycling in New York: The case of Citibike. *J. Transp. Geogr.* **2019**, *77*, 97–112. [CrossRef]
51. Hong, J.; McArthur, D.P.; Stewart, J.L. Can providing safe cycling infrastructure encourage people to cycle more when it rains? The use of crowdsourced cycling data (Strava). *Transp. Res. Part A Policy Pract.* **2020**, *133*, 109–121. [CrossRef]
52. Carslaw, D. worldmet: Import Surface Meteorological Data from NOAA Integrated Surface Database (ISD). Available online: https://CRAN.R-project.org/package=worldmethttps://CRAN.R-project.org/package=worldmet (accessed on 22 July 2020).
53. Thieurmel, B.; Elmarhraoui, A. suncalc: Compute Sun Position, Susuncalc: Compute Sun Position, Sunlight Phases, Moon Position and Lunar Phase. R Package Version 0.5.0. 2019. Available online: https://cran.r-project.org/web/packages/suncalc/suncalc.pdf (accessed on 23 July 2020).
54. Hyndman, R.J.; Khandakar, Y. Automatic Time Series Forecasting: The forecast Package for R. *J. Stat. Softw.* **2008**, *27*, 1–22. [CrossRef]